FLEET MULTI-CHANNEL BROADCAST TRAFFIC INTENSITY STUDY

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

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by

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June 1972

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 1972

ABSTRACT

This thesis contains the analysis of data of message traffic loads on the Naval Communications Fleet Multi-channel Broadcast System and results of a simulation model of the system under various channel alignments. Distributions of interarrival times, message lengths and requests for screens and reruns are determined from the data. These distributions are used in a simulation model of the Broadcast System. The model is used to compare the average delays caused by backlogs of messages when two channels devoted to a given ship-type are a) used in series with the second channel used to rebroadcast messages from the first channel after a one hour delay, and b) both channels are used in parallel to transmit first-run messages. The results of the simulation show that backlogs are reduced considerably by running the two channels in parallel at all times.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TABLE OF ABBREVIATIONS

AUTODIN	Defense Communications System Automatic Digital Communications Network
COMNAVCOMM	Commander, Naval Communications Command
CDF	Cumulative Distribution Function
CLTMR	Closing Timer (used in the model)
DTG	Date-Time-Group, a message identification, e.g., R 021944Z SEP 71, a Routine message originated on 02 SEP 1971 at time 1944Z (Greenwich Mean Time)
MAPU	Multiple Address Processing Unit
MSG	Message
NAVCALS	Naval Communications Area Local Station
NAVCAMS	Naval Communications Area Master Station
NAVCOMMAREA	Naval Communications Area
NAVCOMMSTA	Naval Communications Station
NAVCOMMSYS	Naval Communications System
NAVCOMMU	Naval Communications Unit
NAVRADSTA	Naval Radio Station
OPTMR	Opening Timer (used in the model)
PR	Priority or Precedence (used in the model)
PREC	Precedence
SCRN	Screen
SCRN REQ	Screen Request
SUBS	Subscriber
SVC	Service
TD	Transmitter Distributor
TTY	Teletype

WORD	A teletype word consists of 5 teletype characters
WPM	Words-Per-Minute
ZULU TIME	Greenwich Mean Time

I. THE PROBLEM

This study concerns the message traffic loads on the Naval Communications Fleet Multi-Channel Broadcast System and the problem of determining the most efficient use of the 8 traffic channels in delivering teletype message traffic to the ships at sea.

The Commander, Naval Communications Command message, R 021944Z SEP 71, officially commissioned this study. A copy of this message is shown in Appendix A for reference and to provide an example of a Naval Communications message.

Appendix B provides background information on the organization of the Naval Communication System and a description of the Fleet Multi-Channel Broadcast System.

A. THE QUESTION AS POSED FOR SOLUTION

The original question as it was posed for this study was: "When a significant backlog of any precedence message exists at a channel pair broadcast position, such that the primary channel delivering first run traffic is overloaded, when should the assigned secondary channel be activated for first run traffic and when that backlog ceases to be significant, when should the secondary channel be deactivated from first run traffic?".

In order to discuss the problem further we must first consider how the primary and secondary channel pairs are aligned and used in different traffic load situations.

B. TYPES OF CHANNEL PAIR OPERATION

Table XVII in Appendix B describes the fleet multi-channel broadcast alignment and the designated use for each of the 8 channels. This study considers only 6 of the 8 channels. We note from Table XVII that these 6 channels form 3 pairs of channels which serve different types of ships copying the broadcast. They are: channels 1 and 2 for the Destroyer force, channels 3 and 4 for the Service, Amphibious and Mine forces and channels 5 and 7 for the major warships. Channels 2, 4 and 7 are each designated for use either as a 1 hour delayed broadcast or as an over-load channel for the primary channels 1, 3 and 5 respectively. This allows these secondary channels to be employed in one of two different ways depending on the traffic load situation.

1. Situation 1

When the traffic load for a channel pair is such that the primary channel is not significantly backlogged the secondary channel is used for the 1 hour delayed rebroadcast of the primary channel's traffic. This alignment thereby provides the subscribers of the channel pair two chances to copy a message correctly and completely. Thus if a sub-scriber misses a message or a portion of a message on the primary channel the subscriber may then wait for one hour and attempt to copy the message on the rebroadcast channel. If the subscriber should miss the message both times he then must use the procedure described, in Appendix B, for obtain-ing the missed message. This configuration assumes that by

providing this redundancy in traffic delivery that the number of service requests for reruns will b reduced compared to having only one opportunity to copy the message. Further, it is noted that, for a subscriber to originate a screen request and to receive a reply and/or the desired rerun, the experienced normal time required for such action is in excess of one hour. Hence the 1 hour delayed rebroadcast appears to provide better service provided all subscribers use the system as this alignment intends.

On the other hand there may be situations in which the urgency of the message is such that the subscriber may not want to wait and gamble on the 1 hour delay, only to possibly miss the message again, or perhaps equipment problems may prevent a subscriber from being able to copy the rebroadcast.

2. Situation 2

This situation provides for the case when the channel pair traffic loads are heavy, and significant backlogs do build up such that a decision has to be made by the NAVCOMMSTA to activate the secondary channel to transmit first run traffic in the same manner as the primary channel. In this case both channels of the pair are used to clear the backlog of traffic that has accumulated and to handle any anticipated increase in traffic arrivals which may cause any increased backlog. At the same time, however, this configuration precludes any facility for rebroadcasting the first run traffic as was described in situation 1 above. It is also assumed that this configuration will also prompt

more screen requests to be initiated by the subscribers since it intuitively seems reasonable that more messages may be missed since twice as much first run traffic is being delivered to the subscribers of the channel pair.

In cases where a broadcast channel has no delayed rebroadcast facility use is made of what is called "heading recaps." Heading recaps are a periodic rebroadcast of the headings of messages previously transmitted on that particular channel. Although the broadcast of the heading recaps will consume some of the valuable times needed for transmitting messages which are backlogged it is reasoned that this feature will have an effect of cutting down on the number of screen requests which were prompted because the subscriber was trying to determine only if a missed message was of concern.

Figure 1 diagramatically displays the above described situations, where channels 1 and 2 were the chosen channel pair for illustration.

C. DISCUSSION OF THE PROBLEM

Under conditions when no "significant" backlog of any message precedence exists the channel pair operation will operate as described in situation 1 above. However when a "significant" backlog starts to build up it may then be necessary to use situation 2 in order to make a more timely and efficient delivery of the traffic.

The problem of this study is to determine what is meant by a "significant" backlog and thus determine the point at

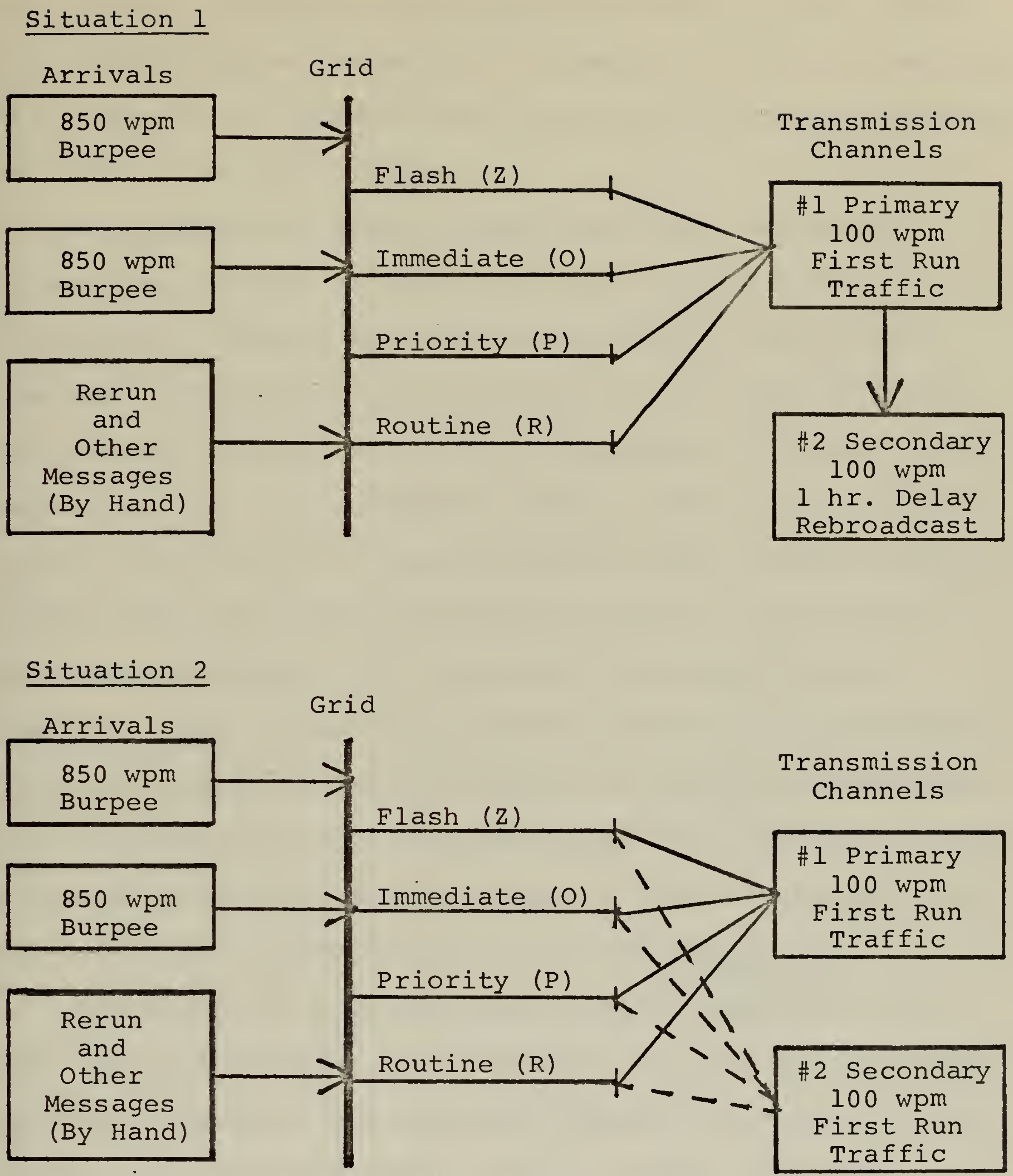


Figure 1. Types of Channel Pair Operation.

which the channel pair is switched from situation 1 to 2, or vice versa. At present this decision is mad by (i) observing how the system has behaved in the past, (ii) by observing the system in its present state, and (iii) by using experience to predict the future state.

The experienced communicator knows that the traffic arrival rate at the broadcast position follows a diurnal fluctuation. He has also observed when the channel pair operation was changed to the situation 2 alignment that the service desk after a time delay experienced a surge of screen requests since the rebroadcast channel facility was discontinued. This surge of screen requests which produce message reruns will most likely contribute further to the backlog and thus the backlog will get worse rather than better. Therefore when the backlog becomes significant the decision maker may decide to hold the system in situation 1 and hope that things get better, or he may make the decision to go to situation 2 and hope that the surge of screen requests does not contribute to the backlog in a significant way.

This method of decision making leaves something to be desired and this study was conducted in order to investigate the two alternate situations and to determine values of the decision variable for when switching should take place.

When the NAVCOMMSTA activates the secondary channel for first run traffic, rather than as a rebroadcast channel, there is a 30 minute delay requirement between notification to the subscribers and the time the channel is activated.

This delay time used by NAVCOMMSTA San Francisco, and assumed common among other NAVCOMMSTA's, is needed for subscribers to prepare necessary equipment to copy the secondary channel all the time. Notification of the intent to activate the secondary channel is sent to the subscribers on the primary channel.

II. THE APPROACH TO THE PROBLEM AND ITS SOLUTION

A. THE DECISION VARIABLE

In order to answer the original question it is first necessary to determine when a significant backlog of messages exists. Let us say that a backlog is considered significant if the expected or average time a message of a certain precedence spends in the broadcast queue and transmission system exceeds the limits of the speed of service criteria shown in Table XVI in Appendix B.

Actually the time standard referred to here is smaller than the speed of service criteria in the table, because the message has already spent some time in transmission before reaching the broadcast position.

During the analysis of screen request messages in this study it was observed that these messages took an average of 2 hours in transmission from the originator to the service desk in the NAVCOMMSTA. If we observe that these screen requests are almost always of Immediate or Priority precedence and if their numbers were evenly divided then the average speed of service criteria would be approximately 150 minutes. Thus 80 percent of the average transmission time was used in transmitting the screen request messages from the ship originators to the NAVCOMMSTA. If for example, these messages were not screen requests messages destined for the service desk, but rather for further relay on the

broadcast, we can see that on the average these messages could spend 30 minutes waiting at the broadcast position for transmission before exceeding the average speed of service criteria. We allow however that not all messages arriving at the broadcast position are from ships at sea but that many are from shore establishments and hence the messages were received at the NAVCOMMSTA via the AUTODIN network which has a much faster transmission rate than the 100 wpm ship-shore teletype circuits. Nevertheless it does not appear unreasonable to assume that an arbitrary but conservative revised speed of service criteria standard to be used at the broadcast could be 50 percent of the criteria shown in Table XVI in Appendix B.

Reducing the times in Table XVI by 1/2 would result in times shown in Table I below.

TABLE I

BROADCAST SPEED OF SERVICE CRITERIA

Precedence	Average Speed of Service	Limits
Flash (Z)	As fast as humanly possible	Same
Immediate (O)	15 minutes	15-30 minutes
Priority (P)	1½ hours	30 minutes-3 hours
Routine (R)	3 hours	1½-12 hours

The decision variable of the problem can then be defined as the expected time a message of a certain precedence spends in the broadcast queue and transmission system, i.e., average time in queue plus the average time in transmission. In addition, a measure of effectiveness can be defined to be the time difference between the expected time in system and the broadcast speed of service criteria.

It would then be logical to conclude that if messages of a certain precedence spent more time on the average than is allowed by the broadcast speed of service criteria, the broadcast system is not making timely and efficient delivery of the traffic. Thus if this condition exists for any appreciable period it should be necessary to use both the primary and secondary channels to deliver the traffic.

B. MODELING THE PROBLEM

The type of model which best fits this system is a queueing model. The customers are the messages and the servers are the transmission channels. The system has four priorities or precedences of messages of which the highest precedence is Flash. The Flash message is allowed to preempt any lower precedence. When a flash message preempts another message the preempted message is later rerun from its beginning after the flash message transmission has been completed. A flash message is run three times to ensure receipt by the addressee. The preemptive method described is known as the Preempt Rerun method as opposed to the Preempt Resume method where the preempted messages will

continue transmission from the point at which it was interrupted.

The modeling of the feedback loop of this system is probably the most challenging because of its various time delays. The feedback loop referred to is that part of the system in which screen requests are made by the subscribers and from which the message reruns are generated. This feedback loop has three time delays associated with it plus a message grouping effect and a change in precedence effect.

The first time delay is the period of time between the actual time the message was missed and the time at which a screen request was sent out by the subscriber. This time delay was not analyzed due to the complexities of measurement. The second and third time delays are the time in transmission of the screen request to the NAVCOMMSTA and the time required to process the screen request at the NAVCOMMSTA broadcast service desk.

The grouping effect is caused by the fact that screen requests normally require a number of messages to be screened and this in turn results in the rerun messages being delivered to the broadcast position in groups of messages.

The change in precedence effect is something that has not been previously mentioned. It is observed that the normal precedence assigned to a screen request is either Immediate or Priority even though some of the messages asked for may be of Routine precedence. This is done because

the originator of the screen request senses a greater urgency in obtaining the missed messages because of the above described time delays. This upgrading of precedence then may require the NAVCOMMSTA to answer the screen request at a higher precedence than the precedence of any message referenced in the request.

C. REQUIRED DATA

The data required to analyze this problem falls into three areas. First, data to determine the type of message arrivals at the broadcast position. Second, the message length distribution must be known. Since the transmission rate of the servers is constant at 100 wpm, the message length distributions translate into the service time distributions. Third, data concerning the screen requests is required. It is essential to investigate the time delay involved from the request for a rerun until it is received by the subscriber, as well as various other parameters which will be more fully described later.

D. SUMMARY OF RESULTS

In order to realistically model the problem, data for interarrival times of first run messages, message lengths, and requests for sceens and reruns was analyzed. The following conclusions were made.

i. The first run message interarrival times were fitted to the exponential distribution and thus the arrivals follow a Poisson Process. (See Table II.)

ii. The message lengths were fitted to a hyperexponential distribution with two proportion parameters. (See Table III.)

iii. The interorigination times for screen requests fit the exponential distribution and thus were also concluded to arrive in a Poisson Process. (See Table X.)

iv. The transmission delay distribution for screen requests was fitted to a right shifted exponential distribution. (See Table X.)

v. The delay of a screen request at the service desk was concluded to follow right shifted hyperexponential distribution for high load periods and a right shifted exponential distribution for low volume traffic. (See Table X.)

vi. The number of rerun messages resulting from a screen request was found to be exponentially distributed. (See Table X.)

The relationship of the number of first run messages and the number of subscribers with the number of screens and reruns was analyzed by linear regression. The results indicate that these variables are independent of each other. (See Figures 12-19.)

The GPSS simulation model of a broadcast channel pair was used to simulate the FASW channel pair in various configurations and traffic loads. The configurations simulated and compared by the average level of backlog were: i) channel 2 closed to first run traffic and used as a rebroadcast of channel 1 traffic, ii) channels 1 and 2 both transmitting first run traffic while the rebroadcast facility was not used and iii) channel 2 alternately opened and closed to transmitting first run traffic whenever specified backlogs were exceeded. The result of these simulations was that backlogs were reduced considerably by running the two channels in parallel transmitting first run traffic and reruns.

III. DATA COLLECTION AND ANALYSIS

The primary source of data used in this thesis was NAVCOMMSTA San Francisco located at Stockton, California. The relative close location of Stockton to Monterey, California allowed frequent visits to the NAVCOMMSTA both to talk to personnel at the station and to collect data.

Although the fleet atmosphere of the Eastern Pacific differs from other parts of the world, it is felt that the type of data collected and that in general the analysis results are typical of any NAVCOMMSTA.

All data which was analyzed to determine a goodness of fit to a theoretical probability distribution was analyzed by using the Fortran IV computer program described and shown in Appendix C.

A. FIRST RUN MESSAGE INTERARRIVAL TIMES ANALYSIS

1. Source of Data

The data used for the analysis represented 4 days of traffic received at the channel 1 broadcast position at NAVCOMMSTA San Francisco. The days represented were 5-8 March 1971. The traffic load for these days was a low to medium volume of 142 to 401 messages per day.

2. Analysis Results

In order to show that the messages arrive in a Poisson Process it is necessary to show that the interarrival times are distributed according to the exponential probability distribution.

The data was analyzed for the daily aggregated arrivals and by individual precedences. Table II gives the results of the statistical goodness of fit tests. We see that the Kolmogorov-Smirnov tests indicated rejection of the hypothesis that the interarrival times are distributed exponentially while the Chi-square tests indicated acceptance for all samples except one. This apparent contradiction is explained by noting that the interarrival times were measured to the nearest integer minute. Hence this caused the data to contain groups of data points of equal value, especially for times less than or equal to 3 minutes. As is noted in Appendix C this grouping effect causes the Kolmogorov-Smirnov (K-S) statistic to inflate and hence causes rejection.

Figures 2 and 3 represent the graphic results for All precedences of 5 March, the data for which both statistical tests indicated rejection of the hypothesis. Figures 4 and 5 represent the graphic results for All Precedences of 6 March and are shown for comparison to the 5 March graphs since the chi-square test indicated acceptance of the hypothesis for the 6 March All Precedence data.

From the statistical test results and from graphs of the data it was concluded that the interarrival times could be reasonably assumed to be distributed according to the exponential distribution. Since this data represented only channel 1 arrivals, it is assumed that message arrivals at other channel pairs also arrive in a Poisson Process.

TABLE II. GOODNESS OF FIT RESULTS FOR INTERARRIVAL TIMES

DATE	PREC	SAMPLE SIZE	PARAMETERS EST MEAN	EST STD.DEV.	EST LAMBDA	KOLMOGOROV-SMIRNOV K-S STAT	K-S TABLE	TEST RESULT	CHI-SQUARE DF	STAT	TEST RESULT
5 MAR	ALL	401	3.54	4.87	.2824	.2743	.0803	REJECT	11	36.01	REJECT
	O	46	29.93	35.60	.0334	.1351	.1980	.95	6	7.46	.75
	P	160	8.88	10.93	.1127	.1872	.1269	REJECT	16	24.88	.95
	R	192	7.37	11.98	.1357	.1771	.1157	REJECT	16	23.68	.95
6 MAR	ALL	326	4.36	5.05	.2293	.2577	.0842	REJECT	13	29.51	.995
	O	43	33.07	36.42	.0302	.1344	.2040	.95	5	2.13	.25
	P	121	11.55	14.85	.0866	.1570	.1458	REJECT	15	21.04	.90
	R	160	8.82	10.79	.1133	.1937	.1270	REJECT	16	21.37	.90
7 MAR	ALL	142	9.98	11.66	.1002	.1972	.1349	REJECT	10	15.67	.90
	O	28	48.54	46.64	.0206	.1290	.1980	.99	2	3.01	.90
	P	75	18.69	17.99	.0535	.1467	.1550	.95	10	8.22	.50
	R	37	35.81	40.21	.0279	.1129	.2220	.95	4	9.23	.95
8 MAR	ALL	205	6.87	9.30	.1455	.2000	.1132	REJECT	15	26.22	.975
	O	19	67.68	48.29	.0148	.1277	.2370	.99	0	0.31	N.A.
	P	99	14.18	18.39	.0705	.1675	.1615	REJECT	14	27.83	.99
	R	85	15.31	27.82	.0653	.2102	.1743	REJECT	11	26.70	.995

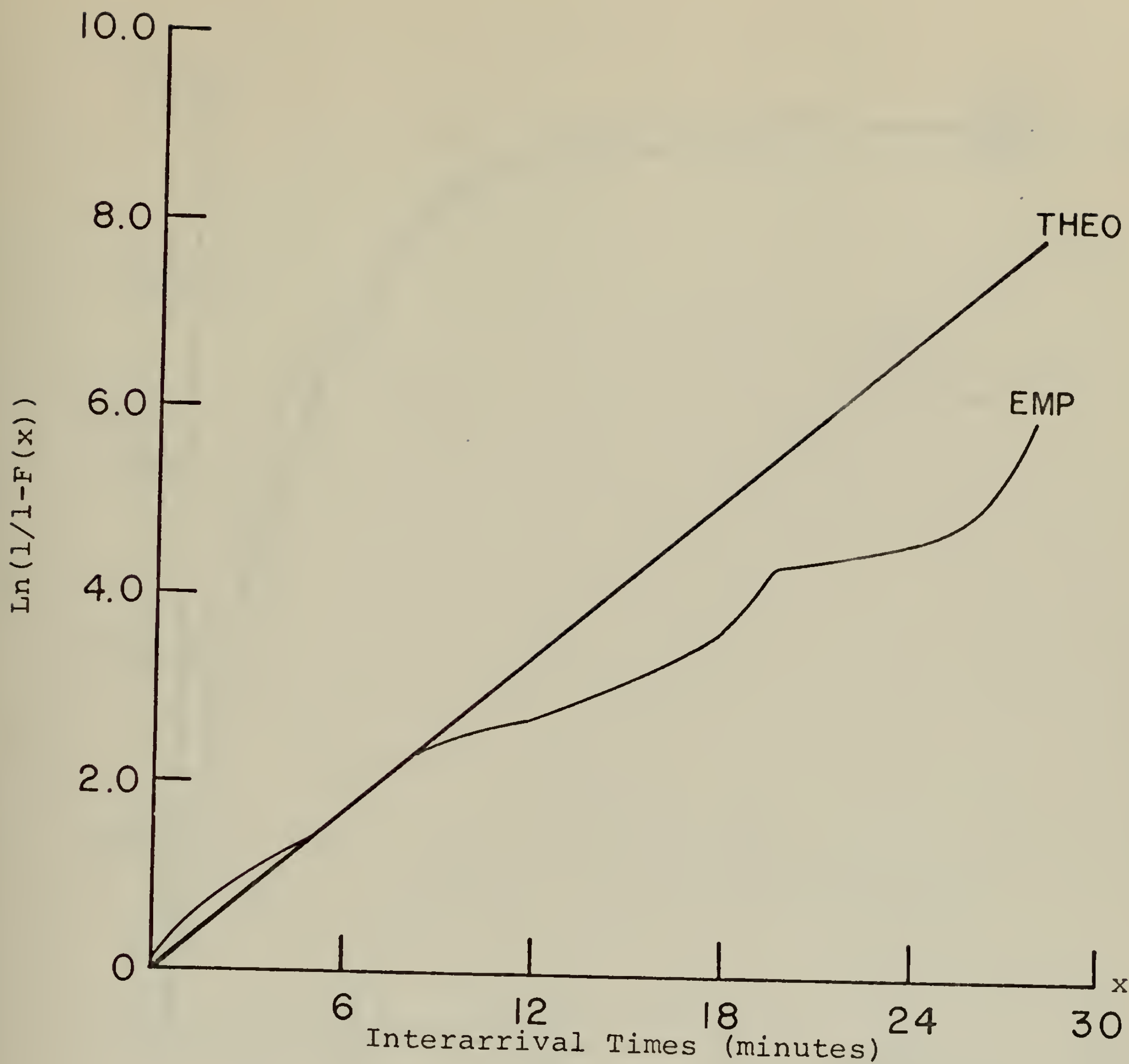


Figure 2. Log of the Tail Distribution for Interarrival Times, 5 MAR., All Precedences.

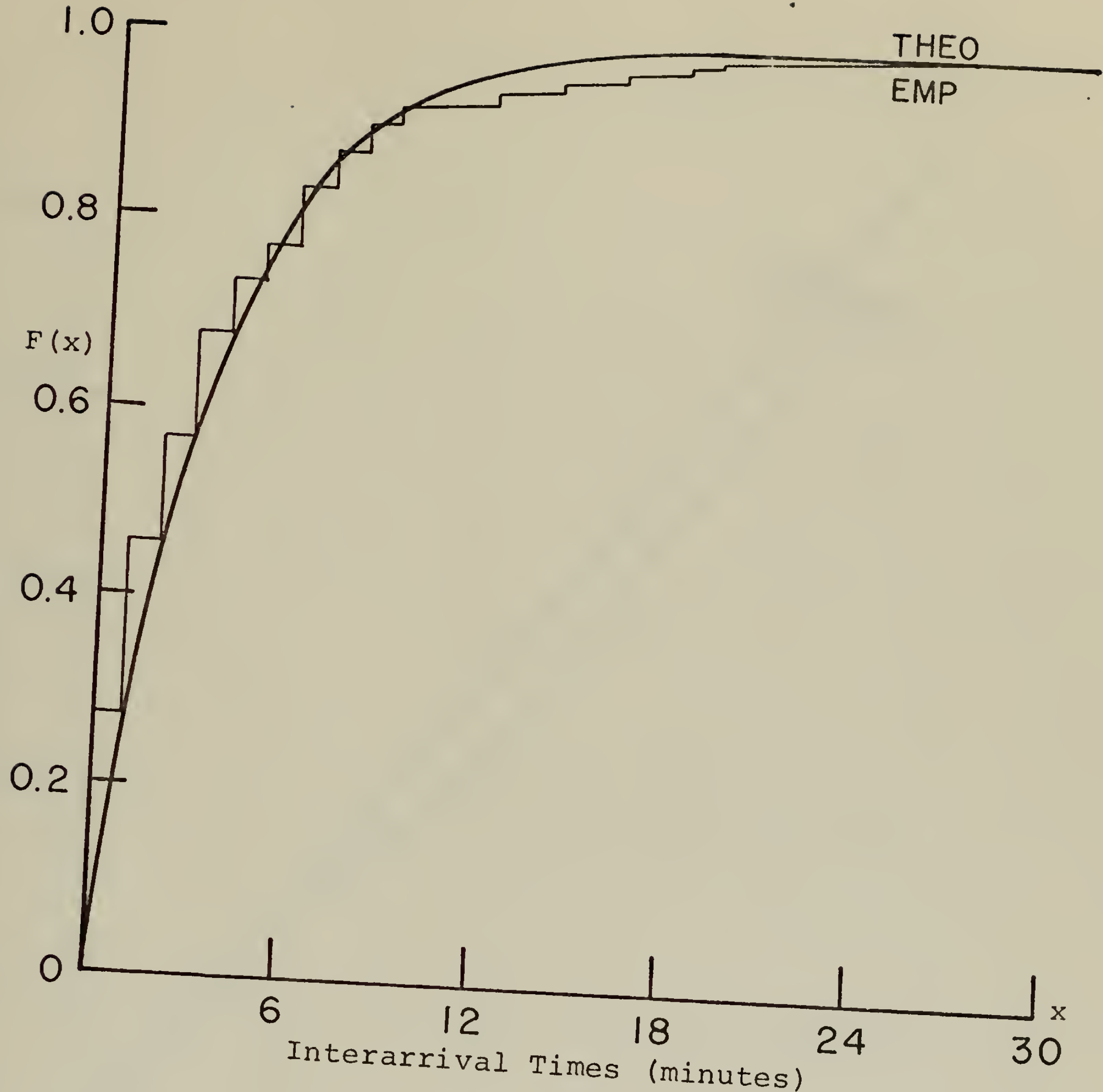


Figure 3. CDFs for Interarrival Times, 5 MAR., All Precedences.

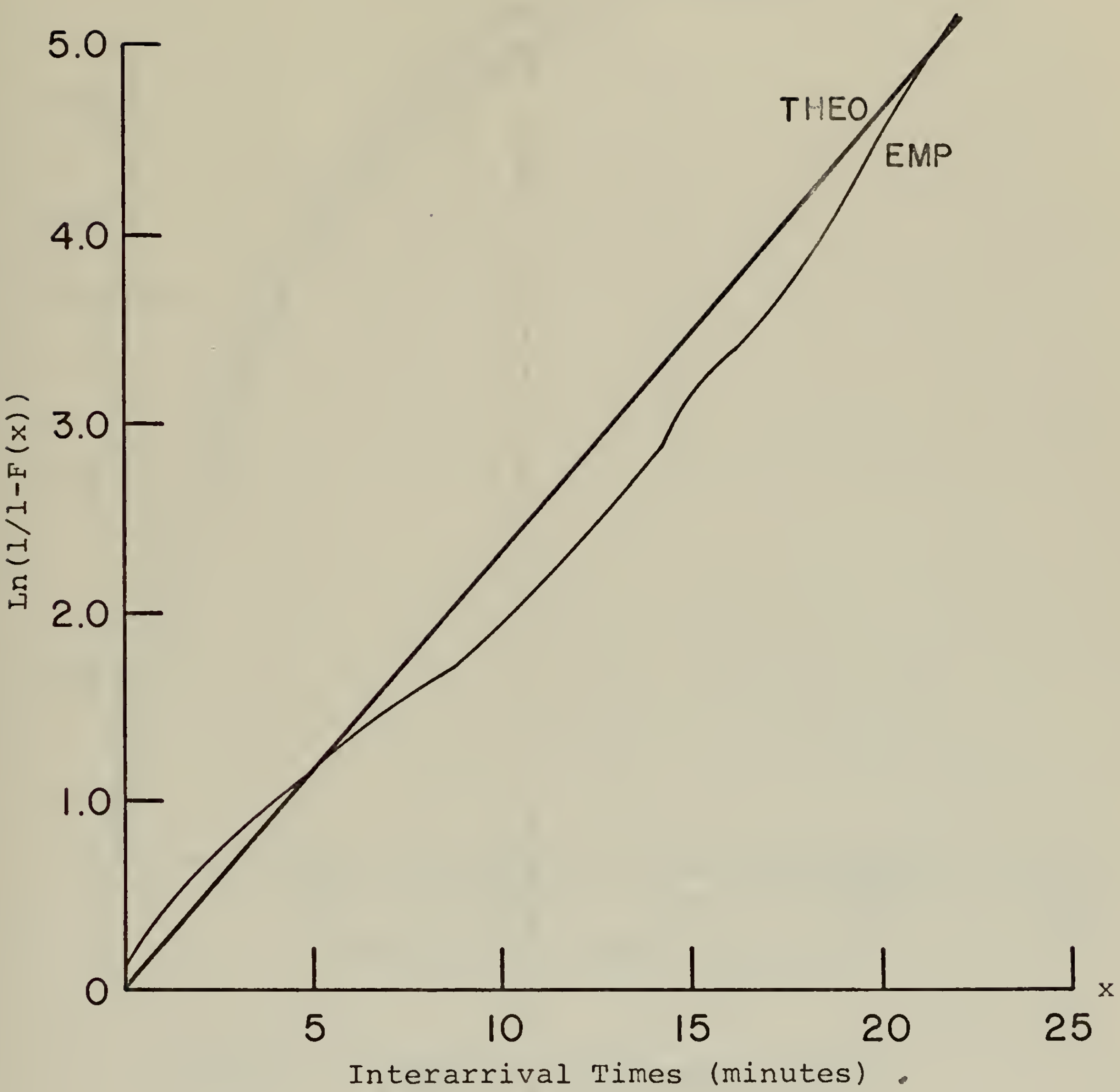


Figure 4. Log of the Tail Distribution for Interarrival Times, 6 MAR, All Precedences.

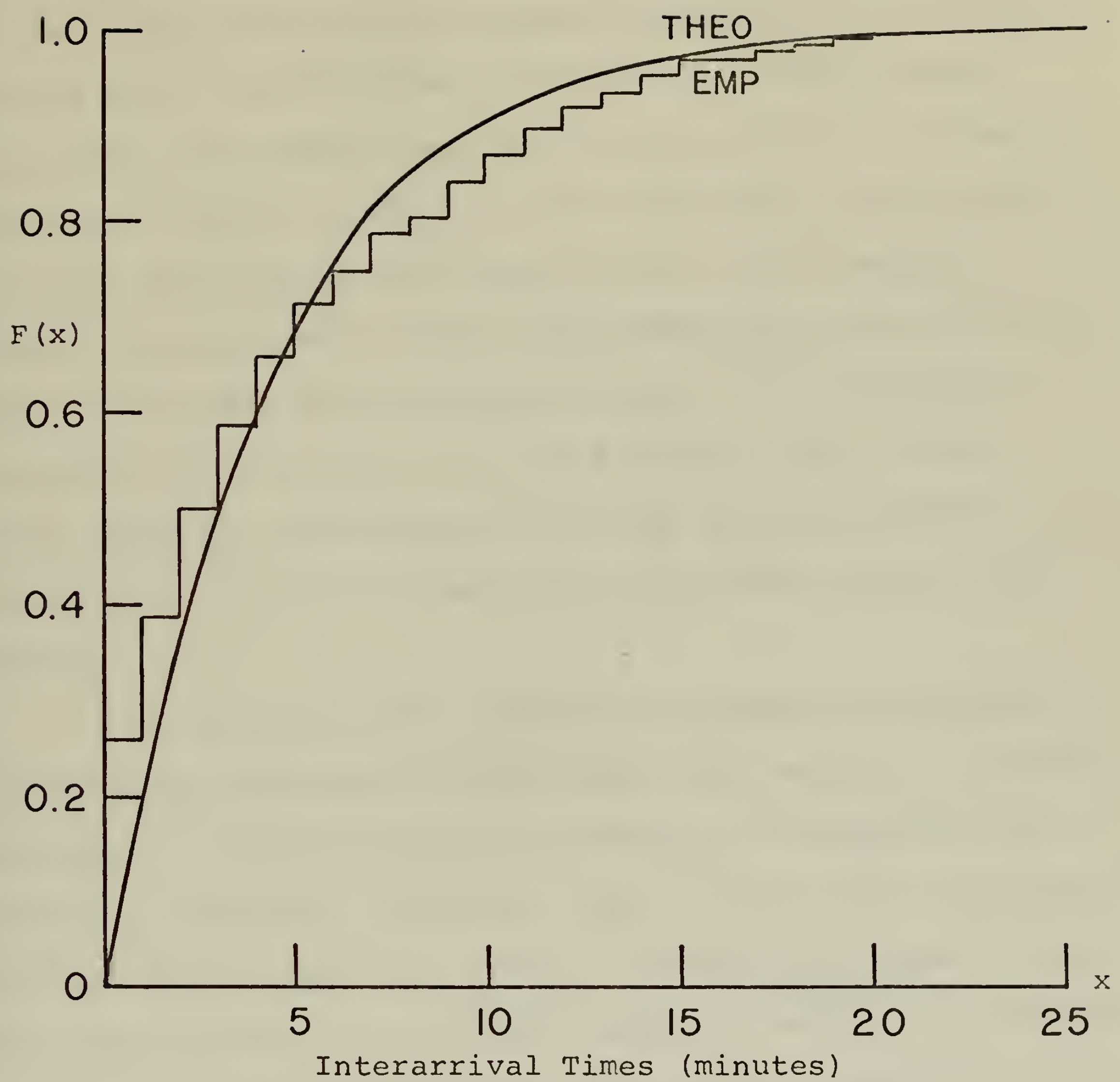


Figure 5. CDFs for Interarrival Times,
6 MAR., All Precedences.

B. MESSAGE LENGTH ANALYSIS

1. Source of Data

The data for message length analysis is from two sources. The first source contains two samples of messages and was taken at NAVCOMMSTA San Francisco. These samples represented the traffic sent on 5 October 1971 on channel 1 (FASW) and channel 5 (FNSC). The other source of data was the Naval Electronics Laboratory Center. This data was obtained from the World Wide Traffic Demand Study data bank and it represents all messages sent on a fleet broadcast in various parts of the world on 8 October 1970. This sample therefore represented the Fleet Broadcast System as a whole and could be assumed not to be biased by any area effects.

The FASW and FNSC samples were taken by measuring the messages in teletype tape form. This method of sampling provides for a high degree of accuracy in determining the length of a message. Teletype tape contains 100 characters per foot which equals 20 words. It should be noted that the tape includes all teletype characters which are processed by the transmitter distributor when sending a message such as spaces, blanks, line feeds, shifts to upper and lower case print, etc., characters which are not easily identified on a printed copy.

The message lengths of the World Wide sample on the other hand were determined by measuring page copies of the messages and using a regression equation to determine the number of words per inch of page copy.

2. Analysis of Message Lengths

The general plan for this analysis was to attempt to fit a probability distribution to the message length data by precedence and then to compare that fit to the world wide sample.

The first fit attempted was the exponential distribution. The results of this showed that the message lengths were not distributed exponentially.

At this point two observations of the above analysis were made. One was that a message has a minimum positive length, since each message has to have a heading which has a date-time-group, an originator and an addressee plus a text. It was estimated that such a minimum would be approximately 20 words long. This led us to fit the data with a right shifted exponential. However, the second observation that was made was that the graphs of the log of the reciprocal of the tail distribution, or simply called the log of the tail, showed that the data in every case had a decreasing failure rate at least for message lengths up to approximately 500 words. One particular distribution with a decreasing failure rate is a mixture of exponential distributions known as the hyperexponential distribution.

These two observations led us to fit the data with a right shifted hyperexponential distribution with two parameters.

The remaining question was whether the FASW and FNSC data which was taken from one day only was representative of

messages sent on other days and on broadcasts throughout the world. This is the primary reason that the world wide sample was obtained.

It was found that the world wide data behaved in the same manner as the FASW and FNSC data and that the right shifted hyperexponential made a very good fit. It was noted however that one of the major differences between the two sets of data was that the world wide data had very few data points which exceeded 1000 words while such data points were very much in presence in the other two samples. Since the analyst personally took the FASW and FNSC samples it was decided that these large data points were not freak outliers, but were very much a part of the distribution. On the other hand it is noted that in reality, message lengths on the broadcast and in general do have an upper bound to their length which is estimated to be approximately 2000 words. This is an apparent contradiction between the empirical and theoretical distributions. It is resolved however by observing that the probability of getting such a long message is indeed very small.

3. Analysis Results

Table III shows the results of the goodness of fit tests for message lengths. It should be pointed out that for all goodness of fit tests that not only were the statistical tests used in making a judgment on the fit but also interpretation of the log of the tail and the Cumulative Distribution Function (CDF) graphs. As is noted in Appendix C, the Chi-square statistic for large sample sizes tends

to inflate and careful attention must be made to the selection of the number of intervals and their widths. In this analysis these drawbacks of the chi-square test were carefully controlled. When the results of the K-S test and the chi-square test conflict we choose the K-S test results unless a graphical interpretation could explain the reason for the rejection result.

We see in Table III that the K-S test results indicate that the hypothesis should be rejected when all precedences are aggregated while only in the case of the FNSC data for all precedences does the chi-square test indicate rejection. Additionally the K-S test indicates rejection for Flash and Immediate precedences for the FNSC data. It is noted that the Flash message samples are included only to give representation of the parameters associated with this precedence since the respective samples were very small and give little meaning to any goodness of fit tests.

Figures 6 through 11 show the log of the tail distribution and CDF graphs for the aggregated precedence for each of the three samples.

In the cases where the Table statistical results indicate rejection for All Precedences of each of the three samples we see that the empirical curve in the log of the tail graph deviated from the theoretical curve in the message length range of greater than 600 words. However the CDF graph shows a reasonably good fit to the theoretical

TABLE III. GOODNESS OF FIT RESULTS FOR MESSAGE LENGTHS

PR	SAMPLE SIZE	EST MEAN	PARAMETERS EST STD.DEV.	EST LAMBDA	PROPORTION P	(1-P)	R.S. A	K-S STAT	K-S TEST RESULT	CHI-SQUARE DF	STAT	TEST RESULT
					FASW							
Z	5	83.0	23.61	.0172	.0390	.9610	25	.5470	.95	0	0.00	N.A.
O	56	245.3	280.52	.0045	.3173	.6827	25	.1488	.95	7	19.79	.995
P	178	257.3	296.04	.0048	.2077	.7923	50	.1133	.99	10	23.07	.99
R	129	182.6	242.13	.0064	.2377	.7623	25	.1325	.99	11	25.26	.995
ALL	368	226.9	275.66	.0051	.2000	.8000	25	.1166	REJECT	9	19.08	.99
					FNSC							
Z	14	91.4	27.20	.0151	.0425	.9575	25	.5554	REJECT	0	9.96	N.A.
O	102	156.3	182.11	.0076	.3052	.6948	25	.1798	REJECT	3	6.00	.90
P	143	317.1	372.15	.0034	.2000	.8000	25	.1354	.99	6	14.19	.975
R	136	203.7	232.36	.0063	.1984	.8016	45	.0996	.90	7	14.98	.975
ALL	395	228.5	286.39	.0049	.2645	.7355	25	.1368	REJECT	6	36.99	REJECT
					WORLD WIDE							
O	24	179.0	101.90	.0078	.1428	.8572	50	.2072	.95	1	5.80	.99
P	103	201.0	209.54	.0060	.3978	.6022	35	.1362	.95	6	14.75	.99
R	138	174.0	179.65	.0065	.4104	.5896	19	.1140	.95	7	5.96	.50
ALL	265	184.9	186.50	.0060	.4538	.5462	19	.1123	REJECT	6	14.82	.99

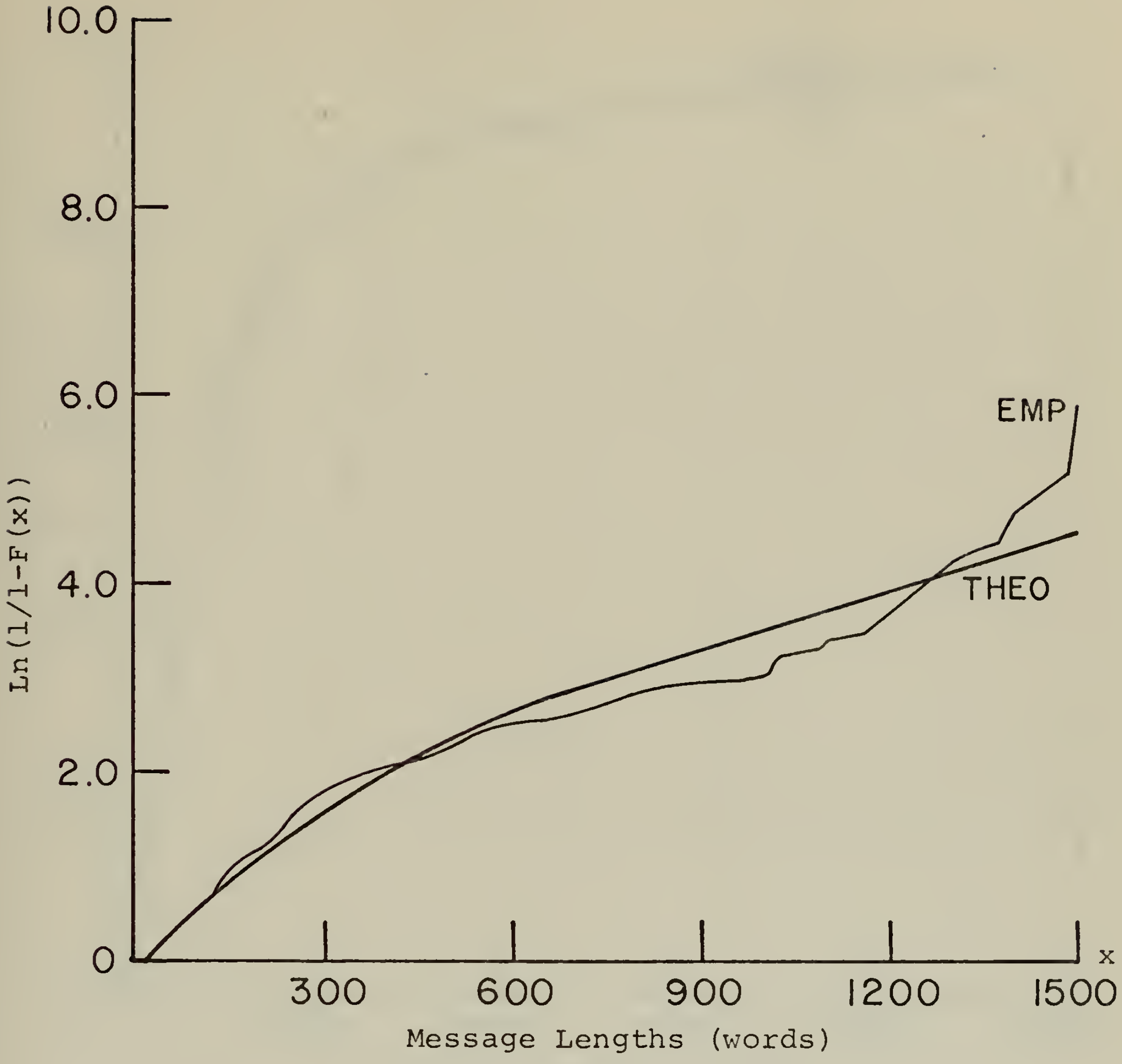


Figure 6. Log of the Tail Distribution for FASW Message Lengths, All Precedences.

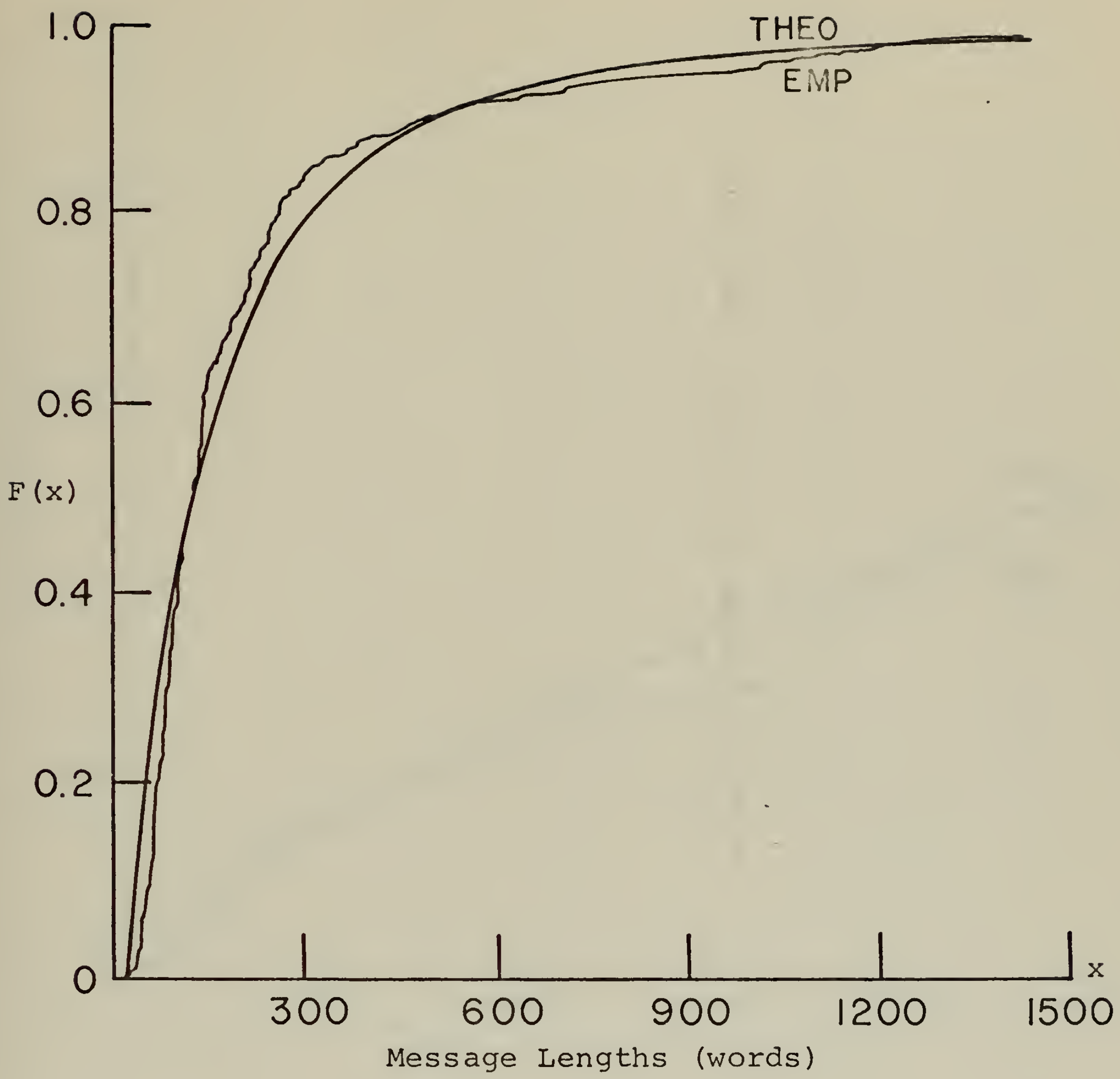


Figure 7. CDFs for FASW Message Lengths, All Precedences.

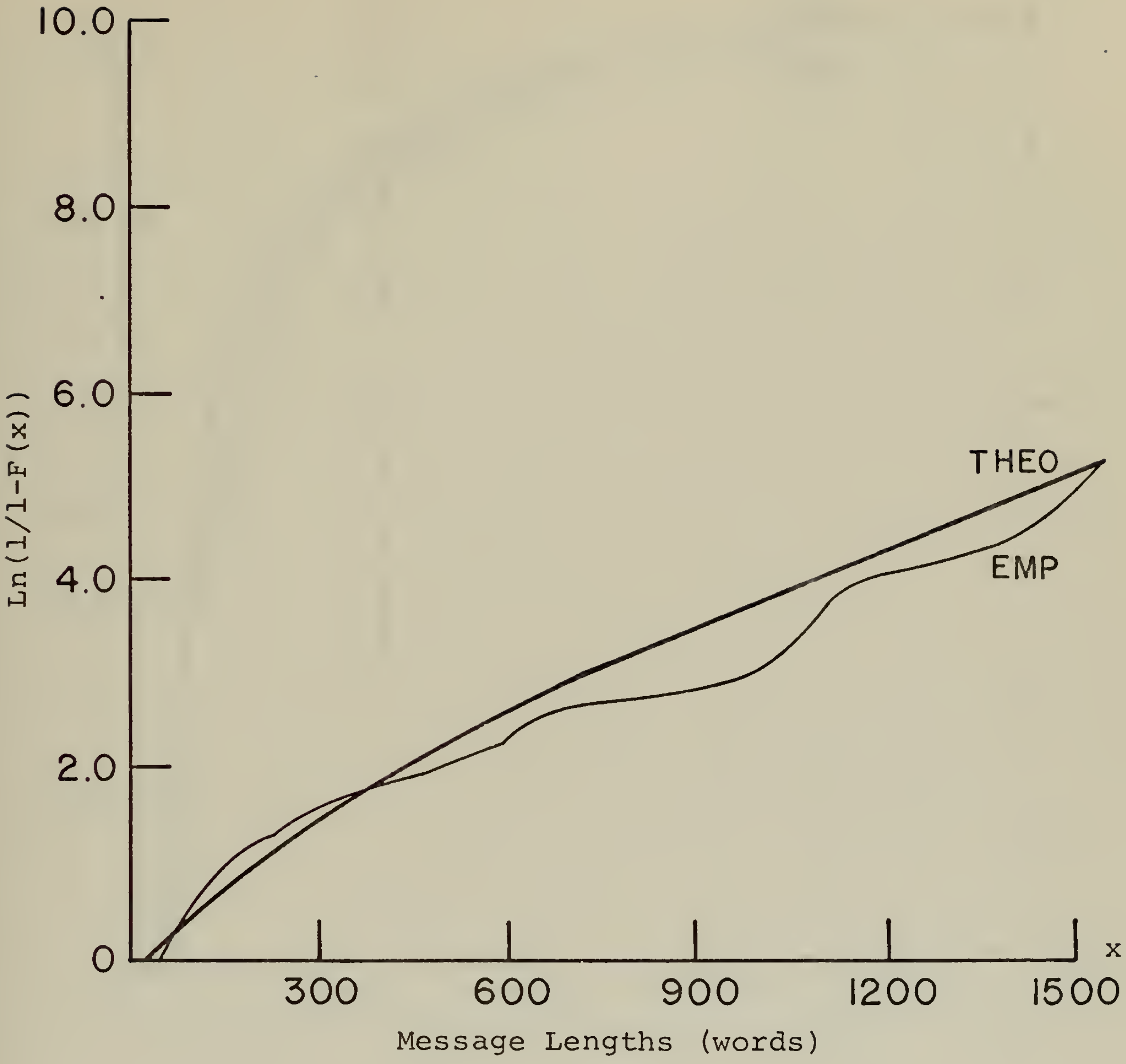


Figure 8. Log of the Tail Distribution for FNSC Message Lengths, All Precedences.

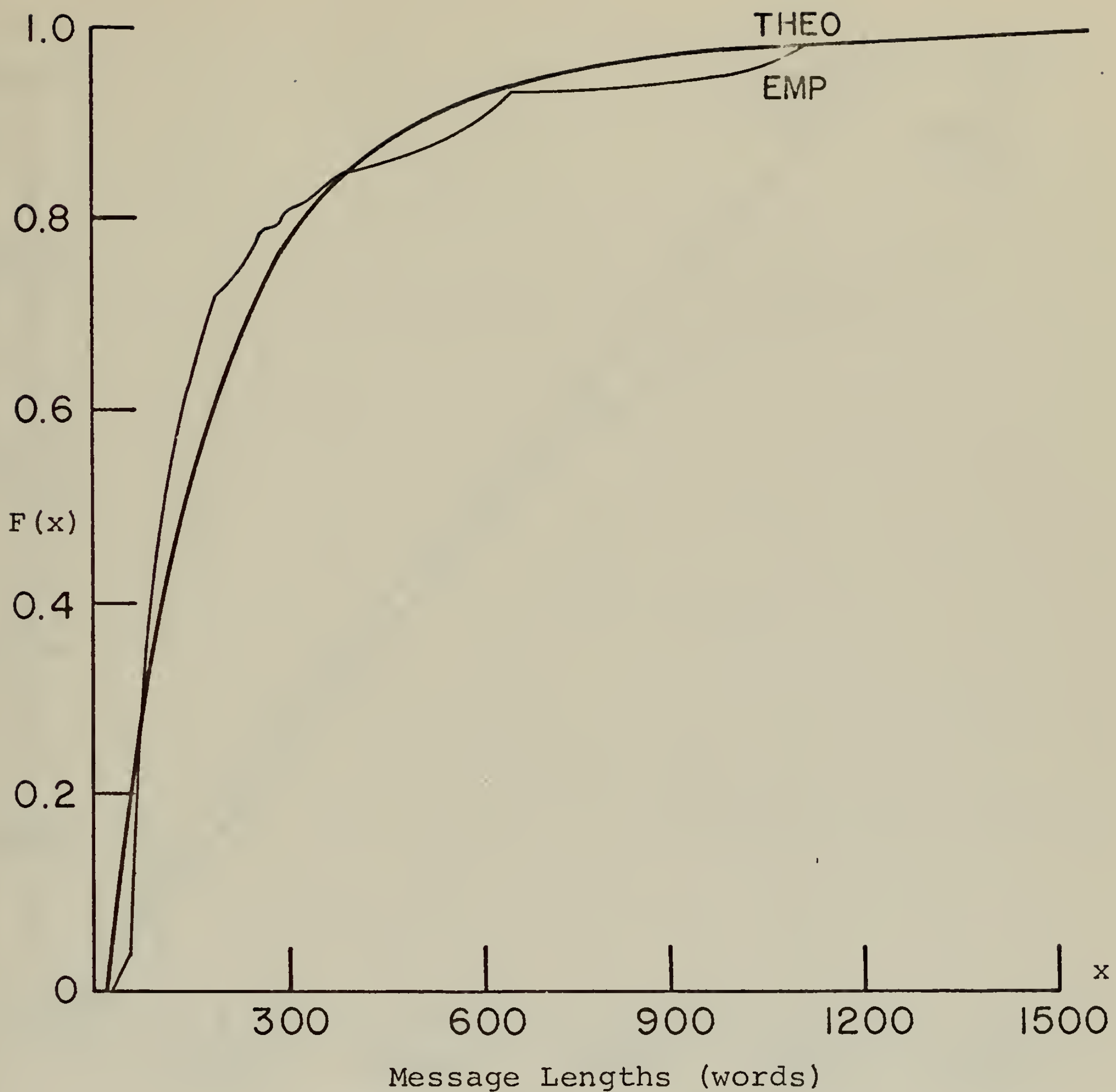


Figure 9. CDFs for FNSC Message Lengths, All Precedences.

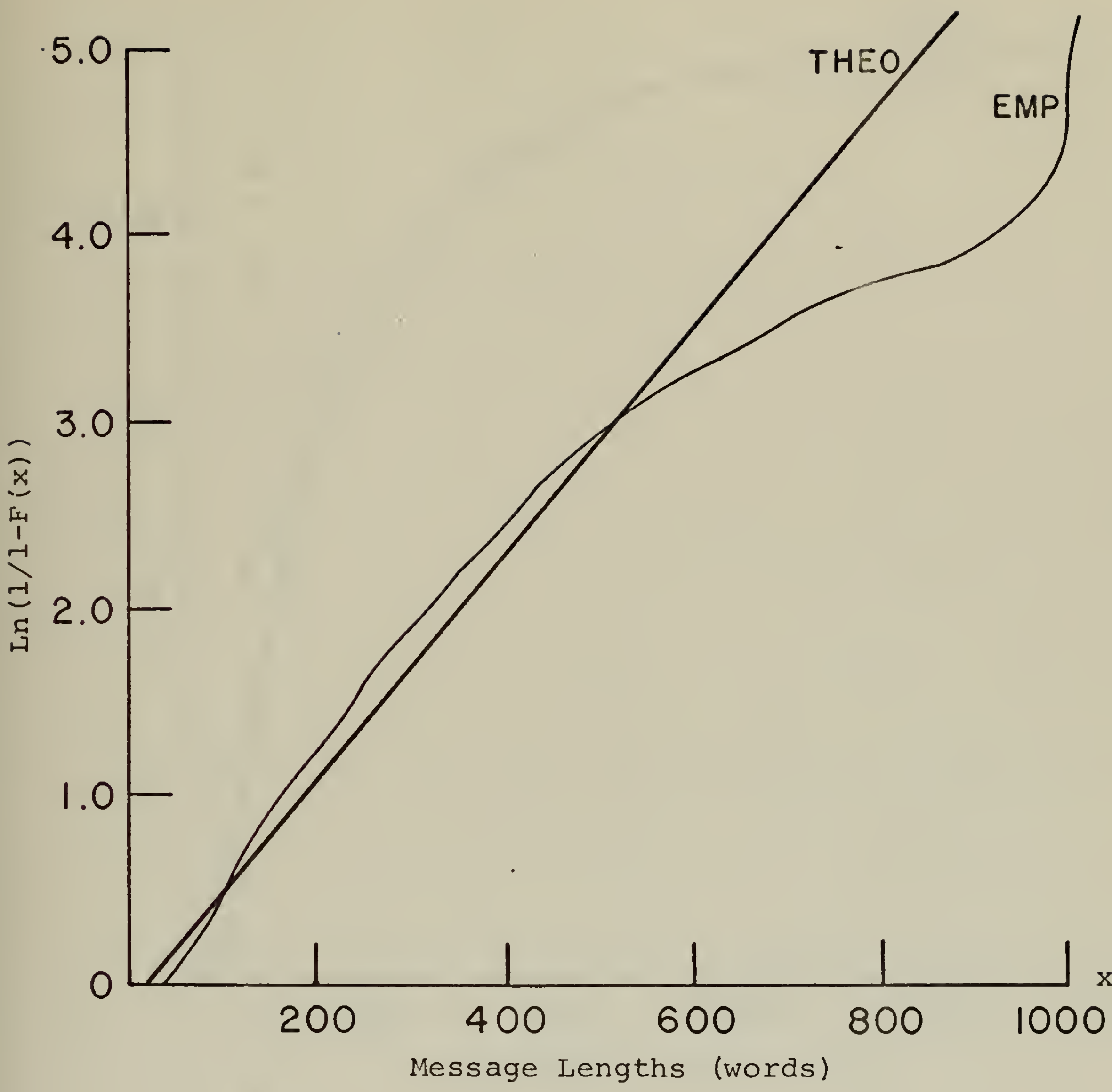


Figure 10. Log of the Tail Distribution for World Wide Message Lengths, All Precedences.

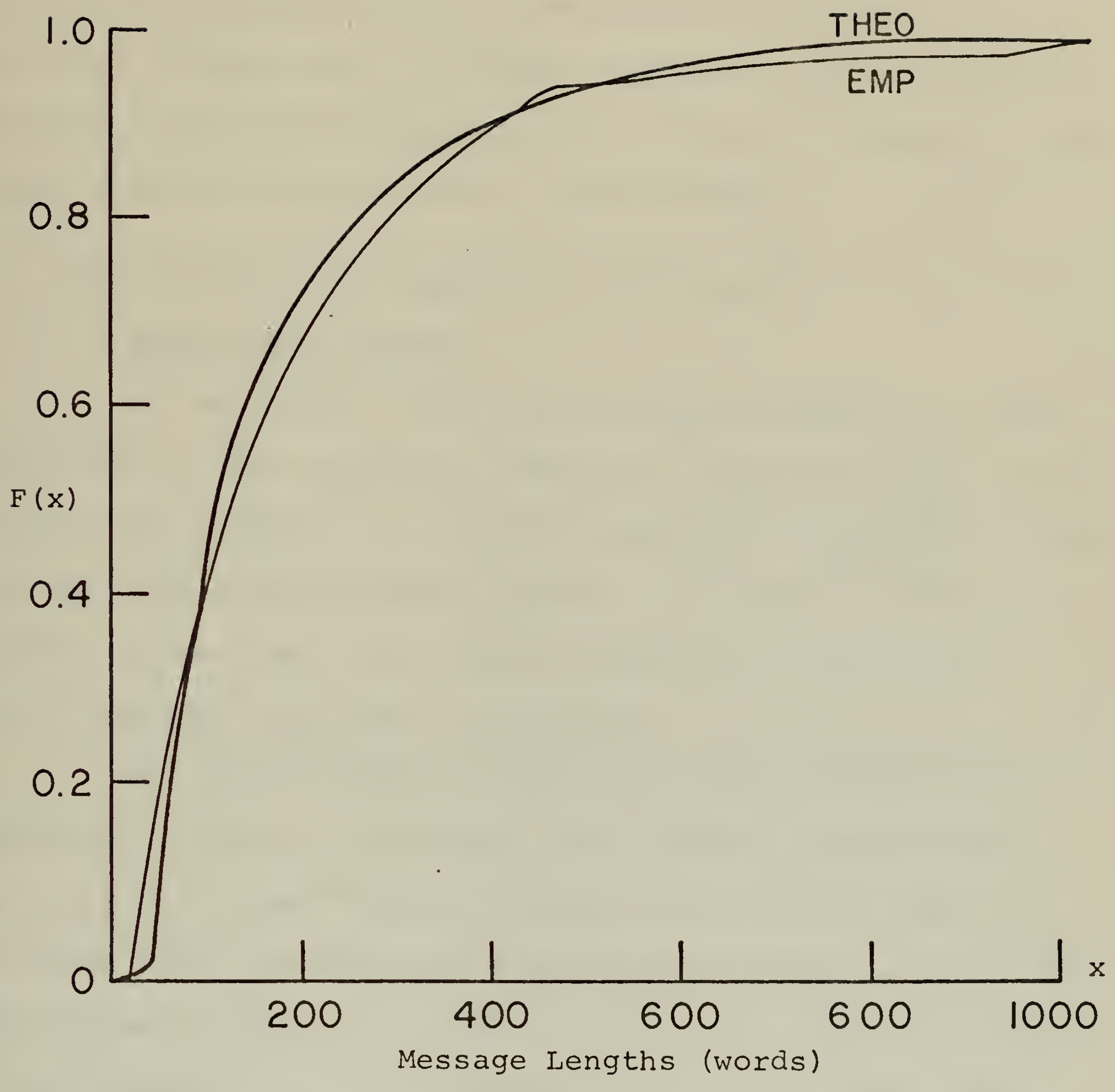


Figure 11. CDFs for World Wide Message Lengths, All Precedences.

distribution. Since the hyperexponential distribution is a mixture of two exponential populations one interpretation is that the message length come from two exponential distributions with the probability or proportion parameters p and 1-p as shown in Table III. It seems reasonable that all message lengths can be considered to be distributed according to the right shifted hyperexponential distribution.

C. SCREEN REQUEST AND FEEDBACK LOOP ANALYSIS

1. Reason for Analysis

The analysis of the entire screen request and feedback loop of this queueing system is a key part to the solution of the problem. For if the system had no feedback then the solution of using both channels of a pair for first run traffic is obvious, since there would be no reason for rebroadcasting the first run traffic.

The investigation of this area poses several new questions. First it is known that a certain percentage of messages are missed during the first run and for some subscribers these messages are successfully copied later on the rebroadcast channel. In order to make some judgment of the effectiveness of the rebroadcast channel we can ask, "How many of the subscribers really do copy the secondary channel?" Next it is known that when messages are missed, that the screen requests usually contain a request for screening more than one message. This implies that the subscribers do wait for a period of time before they ask for screens or they may miss several messages in succession or a mixture of both. This time delay was not analyzed

since it would be very difficult to collect data from the subscribers.

When a screen request is originated there is a transmission delay between the origination time and the receipt by the NAVCOMMSTA. Also, when the screen requests are received by the NAVCOMMSTA there is a time delay for processing the request which is related to the number of messages that have to be screened and to the number of other screen requests waiting at the service desk.

This entire process results in the feedback of messages to the broadcast. The distribution of rerun messages, times between them, and their relationships to the number of subscribers and first run messages must be analyzed.

2. Source of Data

The data for all of the screen requests and feedback loop analysis was obtained from NAVCOMMSTA San Francisco.

3. Number of Subscribers that Copy Rebroadcast Channel

A sample of 14 days of data was available for this analysis. During the period, 26 May-8 June 1971, subscribers were required to report to NAVCOMMSTA San Francisco periodically as to whether they used the rebroadcast channel. Additionally when a subscriber submitted a screen request he was to indicate whether he was using the rebroadcast channel. Table IV indicates the results in average numbers for each channel.

TABLE IV

NUMBER OF SUBSCRIBERS USING
THE REBROADCAST CHANNEL

CHANNEL	NR. 1STRUN	NR. SUBS	NR. SCRNED	NR. RERUN	NR.SUBS REQSCRN	NR. COPY SECONDARY CHANNEL	NR. SUBS REQ SCRN & COPY SECONDARY CHANNEL
FASW	293.1	14.6	26.2	6.5	3.9	3.4 (23.4%)	0.8 (5.8%)
FALD	243.4	19.5	24.8	5.4	2.4	2.6 (13.5%)	0.4 (1.8%)
FNSC	165.9	11.8	39.2	5.1	4.8	3.2 (27.2%)	2.0 (16.9%)

Although this is a small sample and the area location for the sample does not represent the system as a whole it does however show that the secondary channel may not be used to its fullest benefit. If there is to be any conclusion drawn from these results it must be that a surprisingly small percent of the subscribers indicated that they used the rebroadcast channel. An explanation for this may be that the majority of the subscribers either do not desire to wait for an hour to attempt to copy the missed message and instead originate a screen request or they obtain the missed message from another ship.

4. Analysis of the Causes of Reruns

For this analysis two sets of data were available. One set covered the period of 26 May-8 June 1971 and the other the period of 25 August-17 September 1971. The

information in the sample contained daily statistics on the number of first run messages, the number of subscribers copying the channel, the number of screen requests processed, the number of messages required to be screened and the number of messages which had to be rerun. This data represented four different channels, FASW, FALD, FNSC and FRTT, the single channel fleet broadcast which is not part of the multi-channel system.

The August-September data was broken into two parts. During the period 7-17 September a First Fleet Exercise named ROPEVAL 3-71 was conducted and during this period the Operations Evaluation Group (OEG) conducted an experiment of broadcast channel realignment on the FMUL broadcast [1,2]. During this period channel 4 was removed from use as a secondary channel to channel 3 and was converted into a dedicated exercise channel designated XRTT. The XRTT channel carried only exercise traffic to the exercise participants and thereby lightened the load on the other channels during the exercise. This experiment had no direct relationship to this study except that the data collected during the pre-ROPEVAL period and the ROPEVAL period did provide for some comparisons. One such comparison was in the channel 3-4 configuration. Here the subscribers had a backup channel for rebroadcast for one period while during the exercise they did not and hence this would hopefully provide some insight into the effectiveness of the rebroadcast channel.

The exercise time period also provided for moderately high traffic loads and a larger number of subscribers. Additionally the exercise channel XRTT provided an opportunity to look at a high volume of traffic being transmitted under simulated wartime conditions while this channel also had no backup channel for rebroadcast but used only heading recaps as did channel 3 during this period.

Various statistics on screened and rerun messages, called service statistics, are shown for the various channels during the August-September period in Tables V-IX and for the May-June period in Tables XVIII-XXI in Appendix D. These service statistics show no obvious relationships.

In the service statistics Tables the Service Request Rate is abbreviated SVC REQ RATE, and is determined by the following equation:

$$\text{SVC REQ RATE} = \frac{\text{Nr. Messages Screened}}{(\text{Nr. First Run})(\text{Nr. of Subscribers})} .$$

This rate is used by some analysts of communications as a measure of feedback in the system which includes the relationship of first run messages and subscribers [1]. Due to the great variation of this rate over the periods analyzed it was not clear whether there is in fact any relationship among these three measures. Therefore a simple linear regression analysis was used to determine if any such relationship existed [3]. An attempt was made to determine if there was a linear relationship between the following:

Number of First Run Messages vs. Number of Screens

Number of First Run Messages vs. Number of Reruns

Number of Subscribers vs. Number of Screens

Number of Subscribers vs. Number of Reruns

(Nr. of First Run)(Nr. of Subscribers) vs. Nr. of Screens

(Nr. of First Run)(Nr. of Subscribers) vs. Nr. of Reruns

These relationships were chosen, as in the case of the SVC REQ RATE, because intuitively one would suspect that an increase in the number of first run messages broadcast in a day and/or the number of subscribers copying the channel would lead to an increase in missed messages and reruns.

a. Results of the Statistical and Regression Analysis

An important item in Tables V-IX, and those in Appendix D, is the percentage of first run traffic that result in reruns. This measure indicates the additional work that is placed on the system due to the feedback. We note that generally this percentage is between 2-4% even though the number of first run messages and the number of subscribers vary from channel to channel. Two exceptions are 8.2% for FNSC (Aug-Sep) and 18.2% for XRTT during ROPEVAL 3-71. Recall that ROPEVAL was an exercise simulating wartime conditions and hence this increase of reruns during this period is not surprising. Probably the explanation for this is that the subscribers sensed a greater urgency in obtaining missed messages plus they did not have a rebroadcast channel associated with XRTT. This would tend to indicate that the rebroadcast channel may be an effective

feature of the system. On the other hand recall that during the ROPEVAL period channel 3 was operating without a rebroadcast channel as a backup. Looking at the pre-ROPEVAL and ROPEVAL period for channel 3, in Table VI we see that the percent of reruns rose 1.3% while the number of first run messages and the number of subscribers were also greater during the ROPEVAL period. This simple comparison appears to indicate that the presence of the rebroadcast channel had little effect on the number of reruns. An important application of the simulation model (described later) is to resolve these apparently conflicting observations.

Figures 12 through 19 show representative graphs of the regression analysis. All graphs represent the 25 August-17 September period. It is noted that the regression lines were not restricted to go through the origin even though it is obvious that if there were no messages transmitted there would be no feedback. Therefore the reader must be cautioned not to extrapolate the regression line beyond the range of the data shown. In interpreting these graphs one must consider the grouping or spread of the data points and the coefficient of the control variable. For the FASW graphs in Figures 12 and 13 we see that the regression line is nearly horizontal, i.e., it has a slope near 0. This indicates that the number of screens and reruns are independent of the number of first run messages times the number of subscribers.

TABLE V. FASW (CHANNEL 1) AUG-SEP SERVICE STATISTICS

DATE	NR. 1ST RUN MSG	NR. SUBS	NR. SCRND	NR. RERUN	# SCRN REQ	% SCRND	% SCRN	RERUNS/ 1STRUN	SCRNS/ REQ	RERUNS/ REQ	SVC REQ RATE
25 AUG	457.	26.	45.	12.	9.	9.8	26.7	2.6	5.0	1.3	0.0038
26 AUG	391.	21.	54.	12.	9.	13.8	22.2	3.1	6.0	1.3	0.0066
27 AUG	379.	19.	73.	13.	6.	19.3	17.8	3.4	12.2	2.2	0.0101
28 AUG	310.	7.	1.	0.	1.	0.3	0.0	0.0	1.0	0.0	0.0005
29 AUG	148.	7.	5.	1.	2.	3.4	20.0	0.7	2.5	0.5	0.0048
30 AUG	209.	16.	2.	0.	1.	1.0	0.0	0.0	2.0	0.0	0.0006
31 AUG	336.	20.	18.	3.	5.	5.4	16.7	0.9	3.6	0.6	0.0027
01 SEP	340.	17.	36.	12.	2.	10.6	33.3	3.5	18.0	6.0	0.0062
02 SEP	316.	14.	43.	11.	3.	13.6	25.6	3.5	14.3	3.7	0.0097
03 SEP	325.	12.	260.	28.	5.	80.0	10.8	8.6	52.0	5.6	0.0667
04 SEP	306.	12.	68.	27.	5.	22.2	39.7	8.8	13.6	5.4	0.0185
05 SEP	197.	11.	40.	11.	3.	20.3	27.5	5.6	13.3	3.7	0.0185
06 SEP	162.	9.	1.	1.	1.	0.6	100.0	0.6	1.0	1.0	0.0007
SUB TOT	3876.	191.	646.	131.	52.						
AVE	298.2	14.7	49.7	10.1	4.0	16.7	20.3	3.4	12.4	2.5	0.0113
07 SEP	292.	24.	6.	4.	2.	2.1	66.7	1.4	3.0	2.0	0.0009
08 SEP	556.	32.	27.	9.	3.	4.9	33.3	1.6	9.0	3.0	0.0015
09 SEP	607.	38.	65.	16.	7.	10.7	24.6	2.6	9.3	2.3	0.0028
10 SEP	603.	38.	27.	4.	7.	4.5	14.8	0.7	3.9	0.6	0.0012
11 SEP	482.	31.	25.	5.	5.	5.2	20.0	1.0	5.0	1.0	0.0017
12 SEP	323.	31.	24.	7.	6.	7.4	29.2	2.2	4.0	1.2	0.0024
13 SEP	387.	38.	23.	6.	6.	5.9	26.1	1.6	3.8	1.0	0.0016
14 SEP	663.	40.	28.	4.	8.	4.2	14.3	0.6	3.5	0.5	0.0011
15 SEP	617.	40.	82.	10.	13.	13.3	12.2	1.6	6.3	0.8	0.0033
16 SEP	482.	33.	205.	36.	6.	42.5	17.6	7.5	34.2	6.0	0.0129
17 SEP	407.	25.	70.	12.	8.	17.2	17.1	2.9	8.8	1.5	0.0069
SUB TOT	5419.	370.	582.	113.	71.						
AVE	492.6	33.6	52.9	10.3	6.5	10.7	19.4	2.1	8.2	1.6	0.0032
TOTAL	9295.	561.	1228.	244.	123.						
AVE	387.3	23.4	51.2	10.2	5.1	13.2	19.9	2.6	10.0	2.0	0.0057

NOTE: CHANNEL 2 WAS USED AS REBROADCAST CHANNEL FOR THE ENTIRE PERIOD OF 25 AUG-17 SEP.

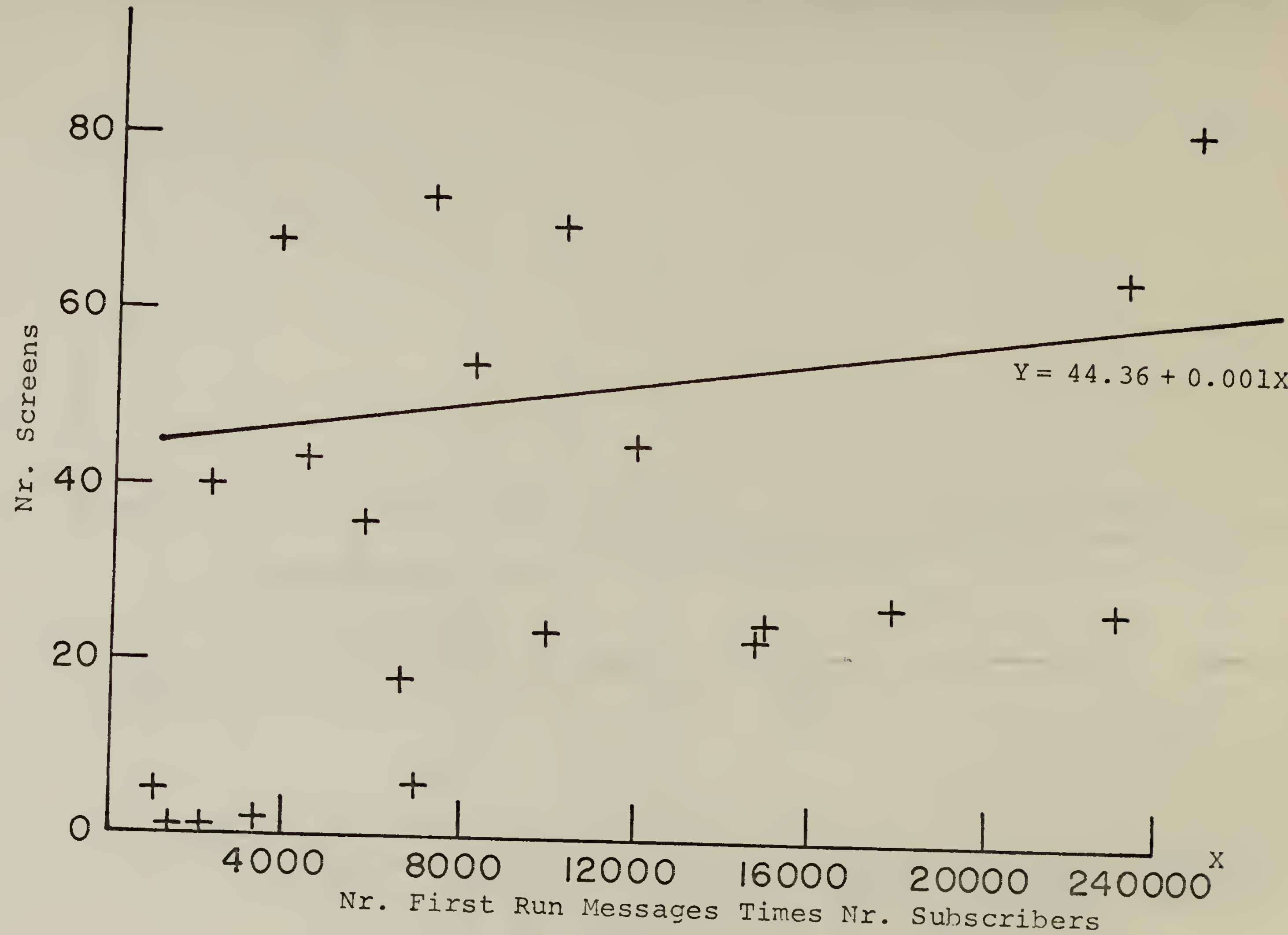


Figure 12. FASW (Nr. First Run)(Nr. Subs) vs. Nr. Screens.

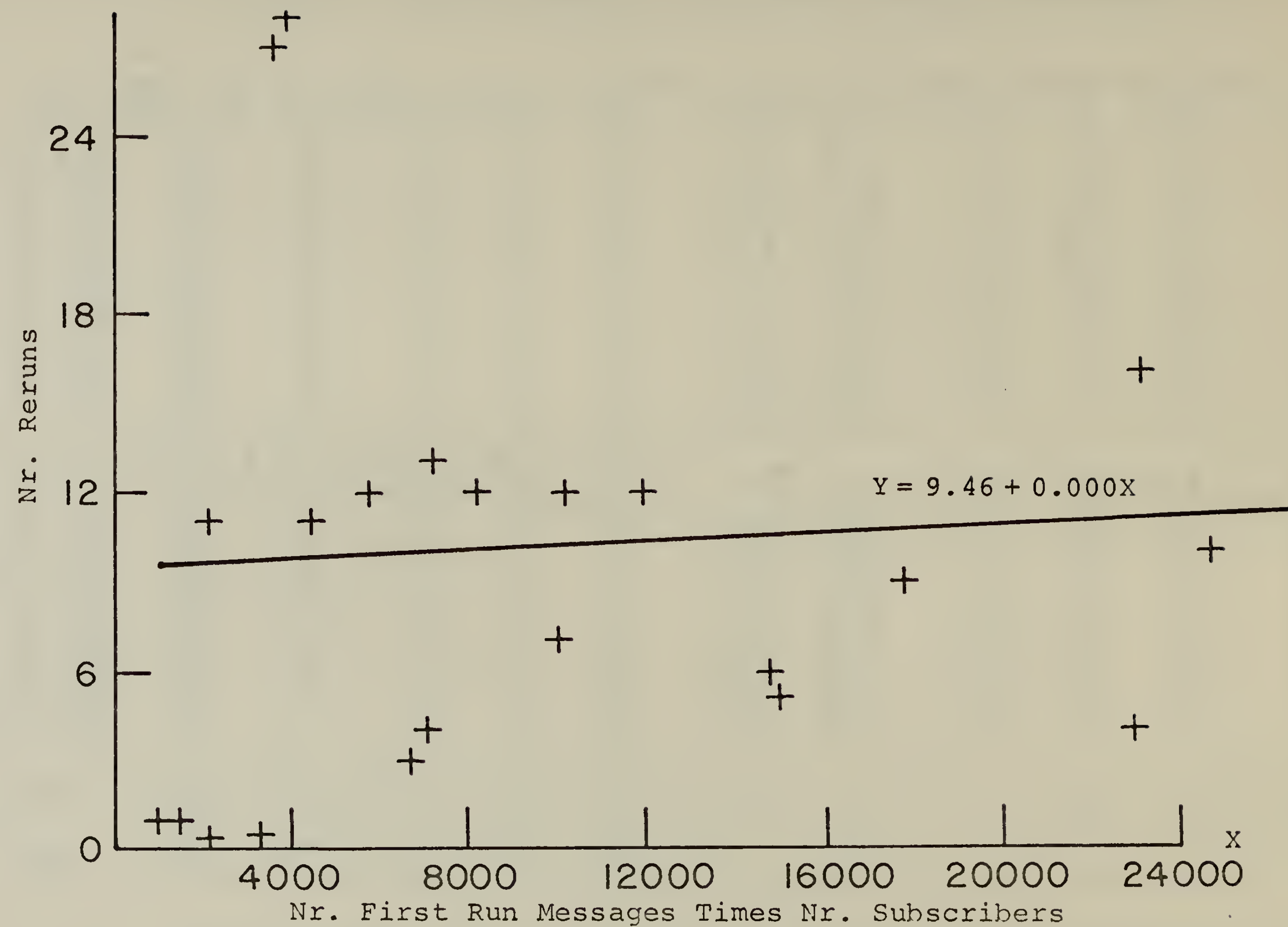


Figure 13. FASW (Nr. First Run)(Nr. Subs) vs. Nr. Reruns.

TABLE VI. FALD (CHANNEL 3) AUG-SEP SERVICE STATISTICS

DATE	NR. 1ST RUN MSG	NR. SUBS	NR. SCRND	NR. RERUN	# SCRN REQ	% SCRND	% SCRN	RERUNS/ 1STRUN	SCRNS/ REQ	RERUNS/ REQ	SVC REQ RATE
25 AUG	324.	26.	4.	3.	2.	1.2	75.0	0.9	2.0	1.5	0.0005
26 AUG	283.	25.	21.	12.	4.	7.4	57.1	4.2	5.3	3.0	0.0030
27 AUG	273.	14.	4.	1.	1.	1.5	25.0	0.4	4.0	1.0	0.0010
28 AUG	297.	14.	58.	5.	3.	19.5	8.6	1.7	19.3	1.7	0.0139
29 AUG	178.	12.	67.	10.	3.	37.6	14.9	5.6	22.3	3.3	0.0314
30 AUG	206.	16.	8.	5.	3.	3.9	62.5	2.4	2.7	1.7	0.0024
31 AUG	286.	16.	15.	1.	3.	5.2	6.7	0.3	5.0	0.3	0.0033
01 SEP	286.	15.	0.	0.	0.	0.0	0.0	0.0	0.0	0.0	0.0
02 SEP	321.	16.	37.	10.	4.	11.5	27.0	3.1	9.3	2.5	0.0072
03 SEP	354.	14.	8.	0.	2.	2.3	0.0	0.0	4.0	0.0	0.0016
04 SEP	285.	10.	5.	2.	3.	1.8	40.0	0.7	1.7	0.7	0.0018
05 SEP	183.	9.	1.	1.	1.	0.5	100.0	0.5	1.0	1.0	0.0006
06 SEP	127.	12.	7.	0.	1.	5.5	0.0	0.0	7.0	0.0	0.0046
SUB TOT	3403.	199.	235.	50.	30.						
AVE	261.8	15.3	19.6	4.2	2.5	7.5	21.3	1.6	7.8	1.7	0.0049
07 SEP	234.	22.	12.	4.	3.	5.1	33.3	1.7	4.0	1.3	0.0023
08 SEP	340.	24.	23.	7.	6.	6.8	30.4	2.1	3.8	1.2	0.0028
09 SEP	338.	26.	203.	21.	7.	60.1	10.3	6.2	29.0	3.0	0.0231
10 SEP	372.	27.	8.	4.	4.	2.2	50.0	1.1	2.0	1.0	0.0008
11 SEP	357.	25.	19.	7.	4.	5.3	36.8	2.0	4.8	1.7	0.0021
12 SEP	215.	26.	96.	15.	6.	44.7	15.6	7.0	16.0	2.5	0.0172
13 SEP	241.	29.	6.	2.	2.	2.5	33.3	0.8	3.0	1.0	0.0009
14 SEP	401.	30.	91.	21.	7.	22.7	23.1	5.2	13.0	3.0	0.0076
15 SEP	381.	28.	66.	12.	8.	17.3	18.2	3.1	8.3	1.5	0.0062
16 SEP	411.	29.	30.	8.	8.	7.3	26.7	1.9	3.8	1.0	0.0025
17 SEP	411.	20.	16.	6.	2.	3.9	37.5	1.5	8.0	3.0	0.0019
SUB TOT	3701.	286.	570.	107.	57.						
AVE	336.5	26.0	52.8	9.7	5.2	15.4	18.8	2.9	10.0	1.9	0.0059
TOTAL	7104.	485.	805.	157.	87.						
AVE	296.0	20.2	33.5	6.5	3.6	11.3	19.5	2.2	9.3	1.8	0.0056

NOTE: CHANNEL 4 WAS USED AS REBROADCAST CHANNEL FOR THE PERIOD 25 AUG-6 SEP ONLY. DURING THE PERIOD 7-17 SEP, CHANNEL 4 WAS REDESIGNATED XRTT CHANNEL AND HEADING RECAPS WERE USED ON CHANNEL 3.

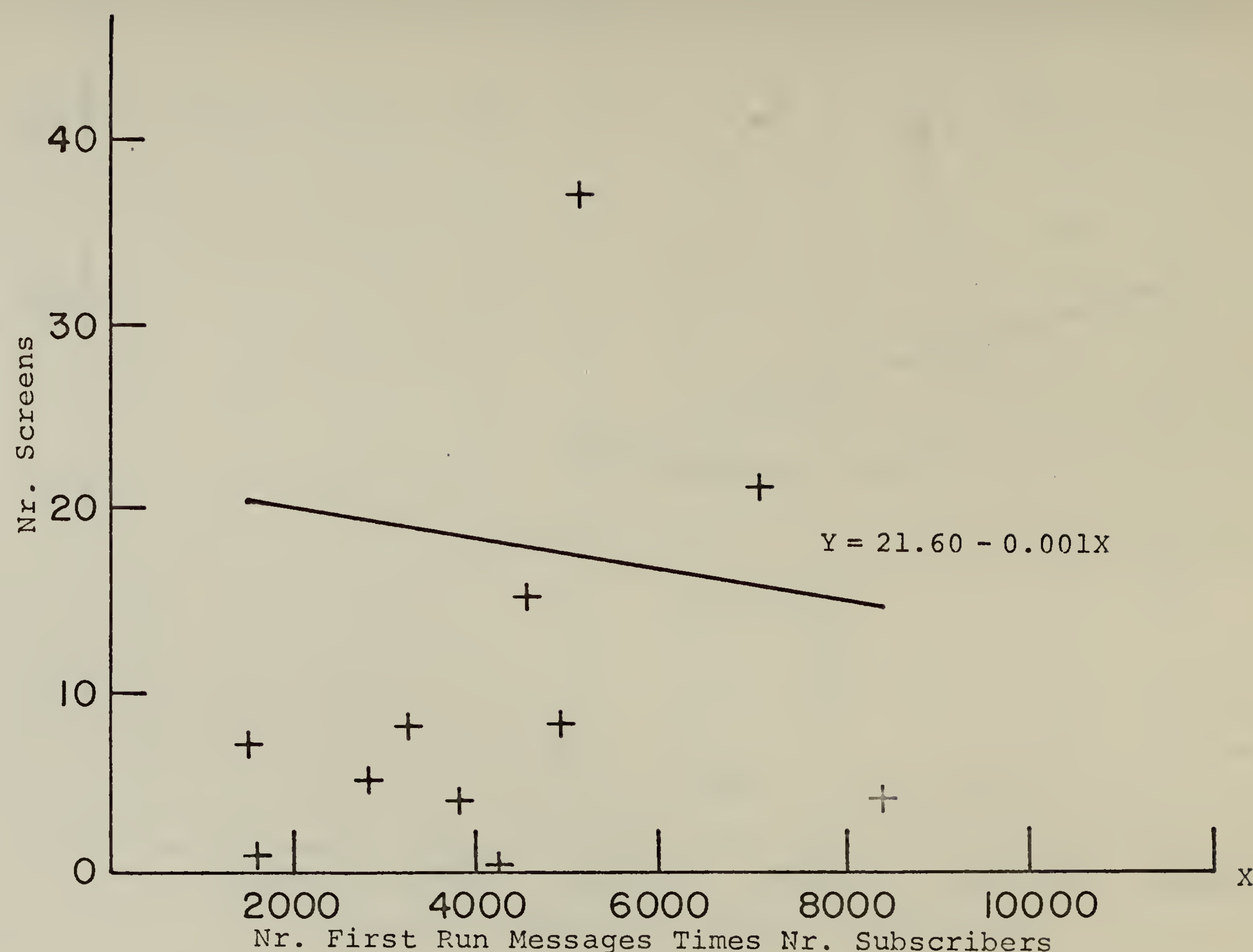


Figure 14. FALD 25 AUG.-6 SEP. (Nr. First Run) (Nr. Subs) vs. Nr. Screens.

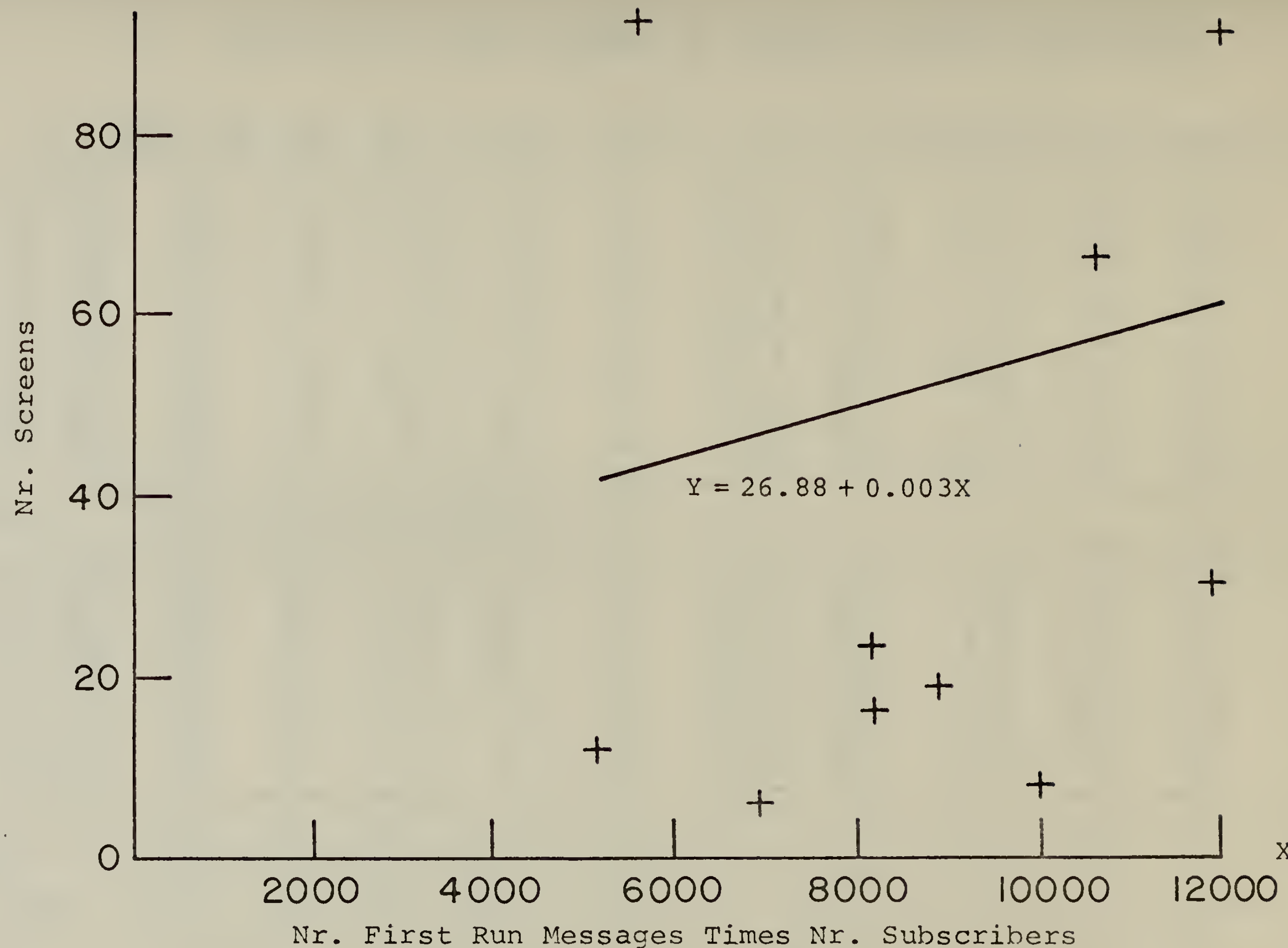


Figure 15. FALD 7-17 SEP. (Nr. First Run) (Nr. Subs) vs. Nr. Screens.

TABLE VII. FNSC (CHANNEL 5) AUG-SEP SERVICE STATISTICS

DATE	NR. 1ST RUN MSG	NR. SUBS	NR. SCRND	NR. RERUN	# SCRN REQ	% SCRND	% SCRN	RERUNS/ 1STRUN	SCRNS/ REQ	RERUNS/ REQ	SVC REQ RATE
25 AUG	211.	10.	121.	21.	11.	57.3	17.4	10.0	11.0	1.9	0.0573
26 AUG	168.	11.	244.	27.	9.	145.2	11.1	16.1	27.1	3.0	0.1320
27 AUG	202.	10.	97.	31.	5.	48.0	32.0	15.3	19.4	6.2	0.0480
28 AUG	243.	10.	67.	9.	5.	27.6	13.4	3.7	13.4	1.8	0.0276
29 AUG	117.	10.	20.	10.	4.	17.1	50.0	8.5	5.0	2.5	0.0171
30 AUG	138.	11.	31.	2.	8.	22.5	6.5	1.4	3.9	0.2	0.0204
31 AUG	191.	11.	42.	22.	7.	22.0	52.4	11.5	6.0	3.1	0.0200
01 SEP	323.	11.	101.	19.	6.	31.3	18.8	5.9	16.8	3.2	0.0284
02 SEP	332.	12.	179.	53.	10.	53.9	29.6	16.0	17.9	5.3	0.0449
03 SEP	285.	13.	113.	23.	11.	39.6	20.4	8.1	10.3	2.1	0.0305
04 SEP	221.	11.	92.	53.	7.	41.6	57.6	24.0	13.1	7.6	0.0378
05 SEP	157.	11.	14.	10.	4.	8.9	71.4	6.4	3.5	2.5	0.0081
06 SEP	201.	13.	93.	42.	6.	46.3	45.2	20.9	15.5	7.0	0.0356
SUB TOT	2789.	144.	1214.	322.	93.						
AVE	214.5	11.1	93.4	24.8	7.2	43.5	26.5	11.5	13.1	3.5	0.0393
07 SEP	242.	17.	23.	11.	6.	9.5	47.8	4.5	3.8	1.8	0.0056
08 SEP	307.	15.	83.	30.	7.	27.0	36.1	9.8	11.9	4.3	0.0180
09 SEP	346.	15.	123.	31.	9.	35.5	25.2	9.0	13.7	3.4	0.0237
10 SEP	402.	15.	81.	20.	12.	20.1	24.7	5.0	6.8	1.7	0.0134
11 SEP	365.	14.	105.	24.	9.	28.8	22.9	6.6	11.7	2.7	0.0205
12 SEP	269.	13.	151.	18.	6.	56.1	11.9	6.7	25.2	3.0	0.0432
13 SEP	343.	15.	43.	7.	5.	12.5	16.3	2.0	8.6	1.4	0.0084
14 SEP	343.	14.	104.	26.	8.	30.3	25.0	7.6	13.0	3.3	0.0217
15 SEP	270.	11.	23.	9.	7.	8.5	39.1	3.3	3.3	1.3	0.0077
16 SEP	261.	14.	31.	6.	13.	11.9	19.4	2.3	2.4	0.5	0.0085
17 SEP	274.	14.	42.	5.	2.	15.3	11.9	1.8	21.0	2.5	0.0109
SUB TOT	3422.	157.	809.	187.	84.						
AVE	311.1	14.3	73.5	17.0	7.6	23.6	23.1	5.5	9.6	2.2	0.0166
TOTAL	6211.	301.	2023.	509.	177.						
AVE	258.8	12.5	84.3	21.2	7.4	32.6	25.2	8.2	11.4	2.9	0.0260

NOTE: CHANNEL 7 WAS USED AS REBROADCAST CHANNEL FOR THE ENTIRE PERIOD OF 25 AUG-17 SEP.

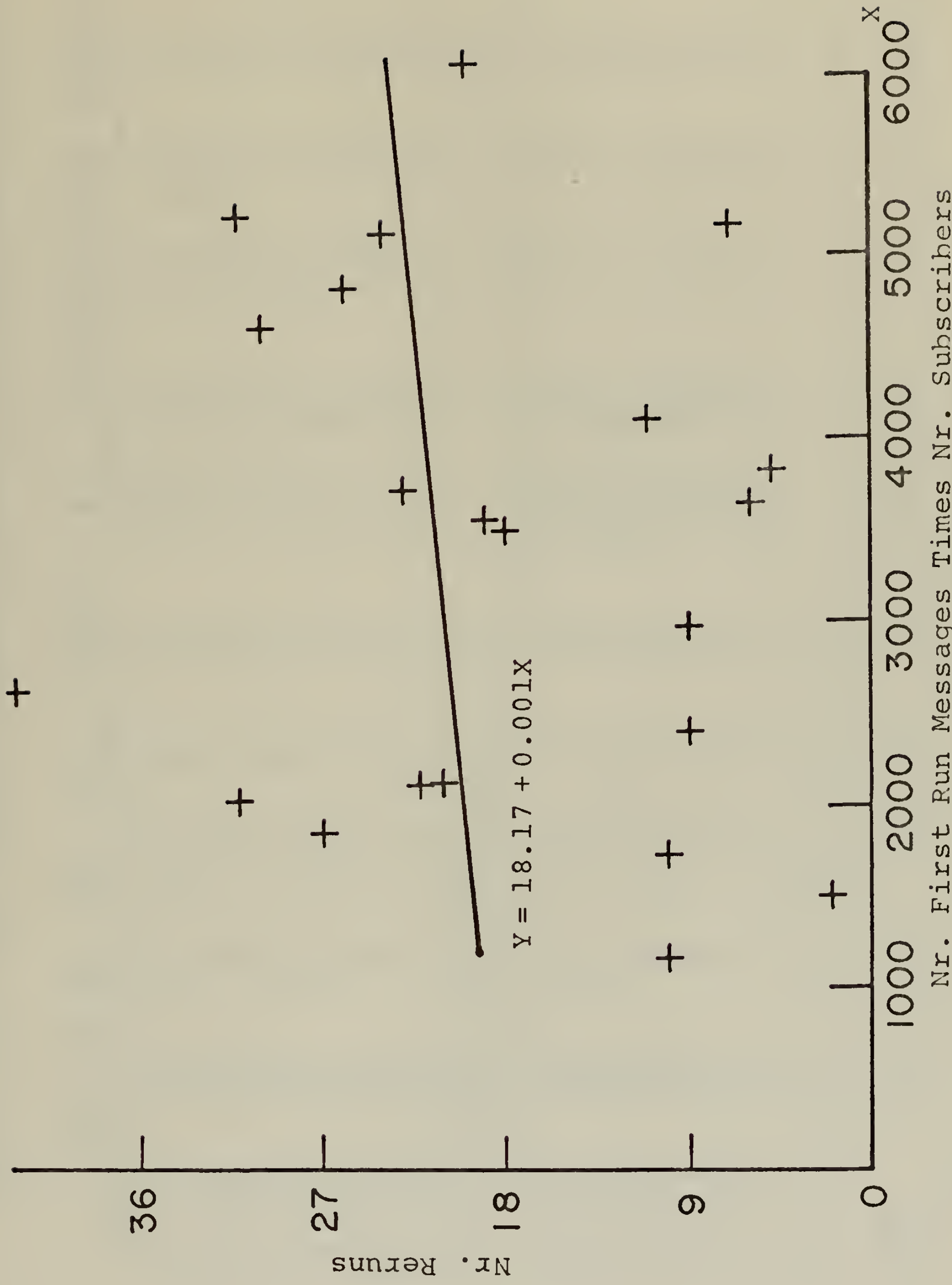


Figure 16. FNSC (Nr. First Run)(Nr. Subs) vs. Nr. Reruns.

TABLE VIII. FRTT (SINGLE NON-FMUL CHANNEL) AUG-SEP SERVICE STATISTICS

DATE	NR. 1ST RUN MSG	NR. SUBS	NR. SCRND	NR. RERUN	# SCRN REQ	% SCRND	% SCRN	RERUNS/ 1STRUN	SCRNS/ REQ	RERUNS/ REQ	SVC REQ RATE
25 AUG	358.	15.	27.	18.	6.	7.5	66.7	5.0	4.5	3.0	0.0050
26 AUG	340.	15.	119.	35.	6.	35.0	29.4	10.3	19.8	5.8	0.0233
27 AUG	349.	14.	31.	5.	3.	8.9	16.1	1.4	10.3	1.7	0.0063
28 AUG	307.	9.	17.	7.	2.	5.5	41.2	2.3	8.5	3.5	0.0062
29 AUG	186.	9.	3.	1.	1.	1.6	33.3	0.5	3.0	1.0	0.0018
30 AUG	232.	11.	7.	2.	1.	3.0	28.6	0.9	7.0	2.0	0.0027
31 AUG	299.	11.	25.	6.	3.	8.4	24.0	2.0	8.3	2.0	0.0076
01 SEP	328.	13.	14.	7.	2.	4.3	50.0	2.1	7.0	3.5	0.0033
02 SEP	315.	12.	18.	8.	2.	5.7	44.4	2.5	9.0	4.0	0.0048
03 SEP	350.	10.	35.	11.	4.	10.0	31.4	3.1	8.8	2.7	0.0100
04 SEP	272.	7.	5.	4.	3.	1.8	80.0	1.5	1.7	1.3	0.0026
05 SEP	206.	7.	61.	18.	6.	29.6	29.5	8.7	10.2	3.0	0.0423
06 SEP	208.	7.	20.	5.	5.	9.6	25.0	2.4	4.0	1.0	0.0137
SUB TOT	3750.	140.	382.	127.	44.						
AVE	288.5	10.8	29.4	19.8	3.4	10.2	33.2	3.4	8.7	2.9	0.0095
07 SEP	262.	10.	16.	7.	4.	6.1	43.8	2.7	4.0	1.8	0.0061
08 SEP	253.	12.	53.	2.	5.	20.9	3.8	0.8	10.6	0.4	0.0175
09 SEP	280.	13.	23.	13.	5.	8.2	56.5	4.6	4.6	2.6	0.0063
10 SEP	306.	12.	54.	17.	4.	17.6	31.5	5.6	13.5	4.2	0.0147
11 SEP	284.	11.	39.	24.	3.	13.7	61.5	8.5	13.0	8.0	0.0125
12 SEP	188.	8.	107.	31.	3.	56.9	29.0	16.5	35.7	10.3	0.0711
13 SEP	216.	9.	18.	5.	1.	8.3	27.8	2.3	18.0	5.0	0.0093
14 SEP	258.	10.	3.	0.	1.	1.2	0.0	0.0	3.0	0.0	0.0012
15 SEP	215.	8.	18.	14.	3.	8.4	77.8	6.5	6.0	4.7	0.0105
16 SEP	224.	6.	5.	1.	1.	2.2	20.0	0.4	5.0	1.0	0.0037
17 SEP	214.	5.	24.	9.	3.	11.2	37.5	4.2	8.0	3.0	0.0224
SUB TOT	2700.	104.	360.	123.	33.						
AVE	245.5	9.5	32.7	11.2	3.0	13.3	34.2	4.6	10.9	3.7	0.0141
TOTAL	6450.	244.	742.	250.	77.						
AVE	268.8	10.2	30.9	10.4	3.2	11.5	33.7	3.9	9.6	3.2	0.0113

NOTE: HEADING RECAPS WERE USED DURING THE ENTIRE PERIOD.

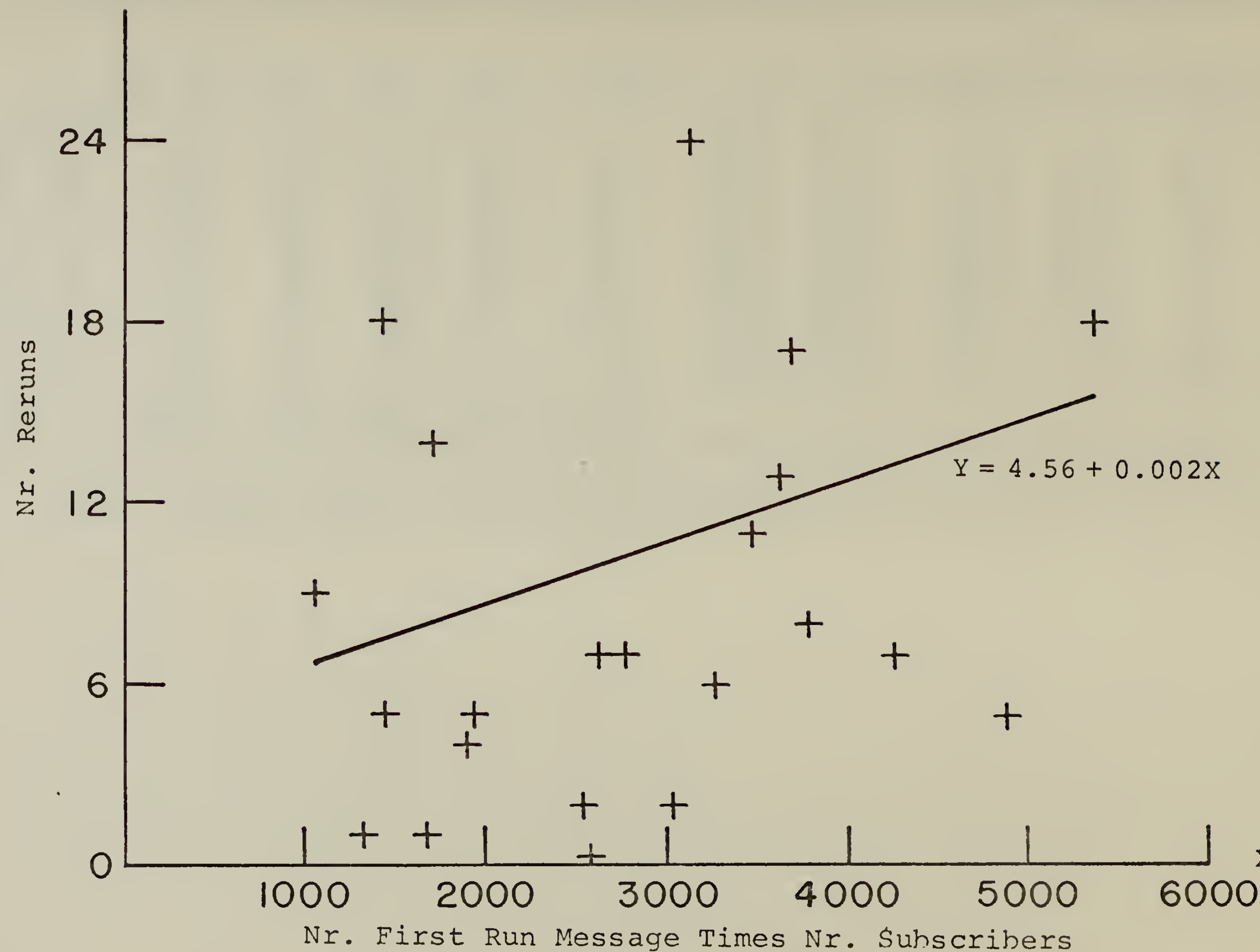


Figure 17. FRTT (Nr. First Run)(Nr. Subs) vs. Nr. Reruns.

TABLE IX. XRTT (DEDICATED EXERCISE CHANNEL) AUG-SEP SERVICE STATISTICS

DATE	NR. 1ST RUN MSG	NR. SUBS	NR. SCRND	NR. RERUN	# SCRN REQ	% SCRND	% SCRN	RERUNS/ 1STRUN	SCRNS/ REQ	RERUNS/ REQ	SVC REQ RATE
07 SEP	55.	41.	6.	1.	2.	10.9	16.7	1.8	3.0	0.5	0.0027
08 SEP	221.	41.	59.	31.	8.	26.7	52.5	14.0	7.4	3.9	0.0065
09 SEP	282.	40.	176.	66.	10.	62.4	37.5	23.4	17.6	6.6	0.0156
10 SEP	360.	40.	169.	61.	14.	46.9	36.1	16.9	12.1	4.4	0.0117
11 SEP	443.	40.	72.	45.	11.	16.3	62.5	10.2	6.5	4.1	0.0041
12 SEP	464.	40.	148.	55.	7.	31.9	37.2	11.9	21.1	7.9	0.0080
13 SEP	355.	40.	145.	67.	10.	40.8	46.2	18.9	14.5	6.7	0.0102
14 SEP	452.	40.	387.	174.	20.	85.6	45.0	38.5	19.3	8.7	0.0214
15 SEP	408.	40.	135.	56.	13.	33.1	41.5	13.7	10.4	4.3	0.0083
16 SEP	204.	40.	93.	42.	11.	45.6	45.2	20.6	8.5	3.8	0.0114
17 SEP	58.	40.	11.	4.	5.	19.0	36.4	6.9	2.2	0.8	0.0047
TOTAL	3302.	442.	1401.	602.	111.						
AVE	300.2	40.2	127.4	54.7	10.1	42.4	43.0	18.2	12.6	5.4	0.0106

NOTE: HEADING RECAPS WERE USED DURING THE ENTIRE PERIOD OF 7-17 SEP.

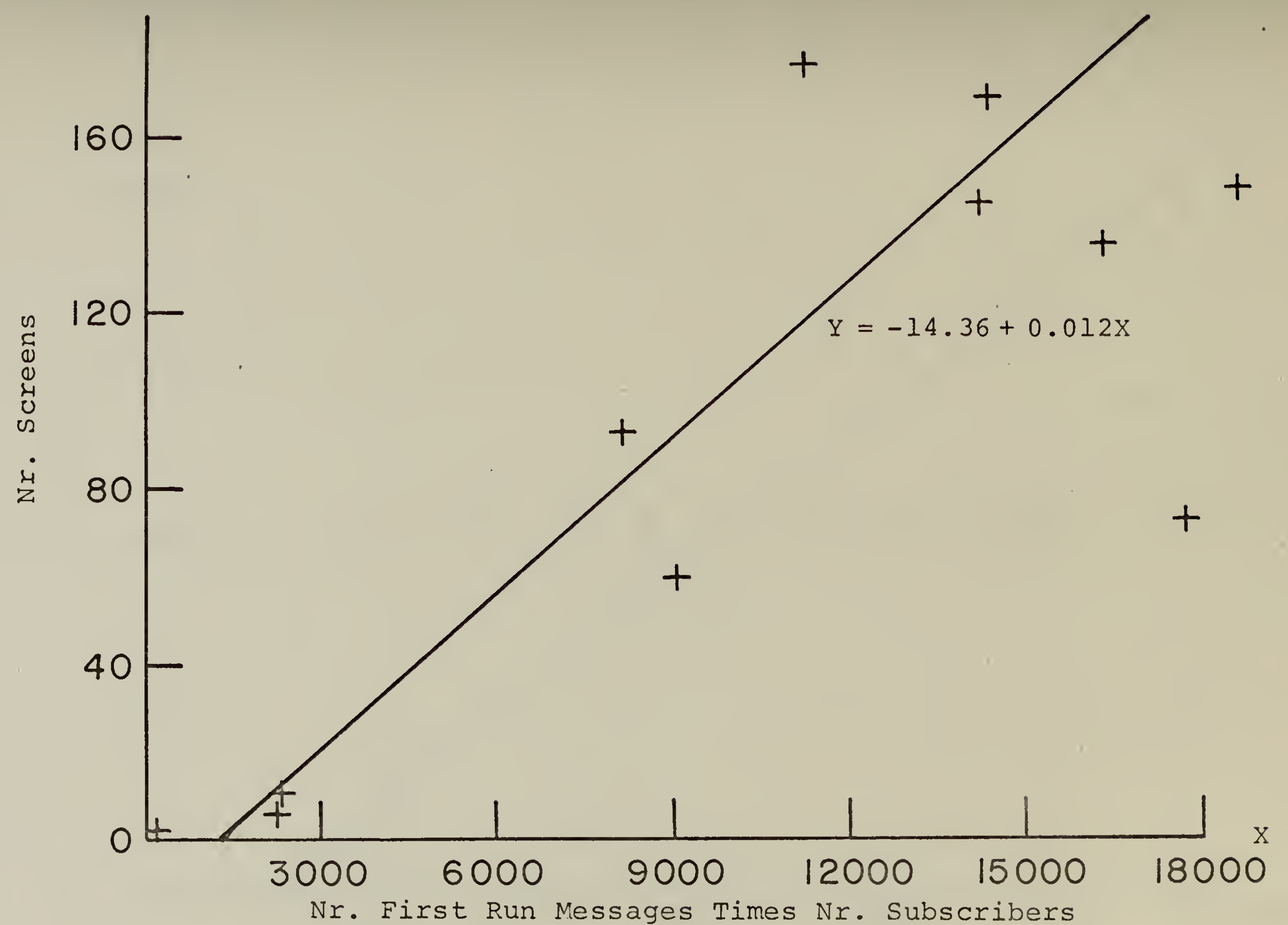


Figure 18. XRTT (Nr. First Run)(Nr. Subs) vs. Nr. Screens.

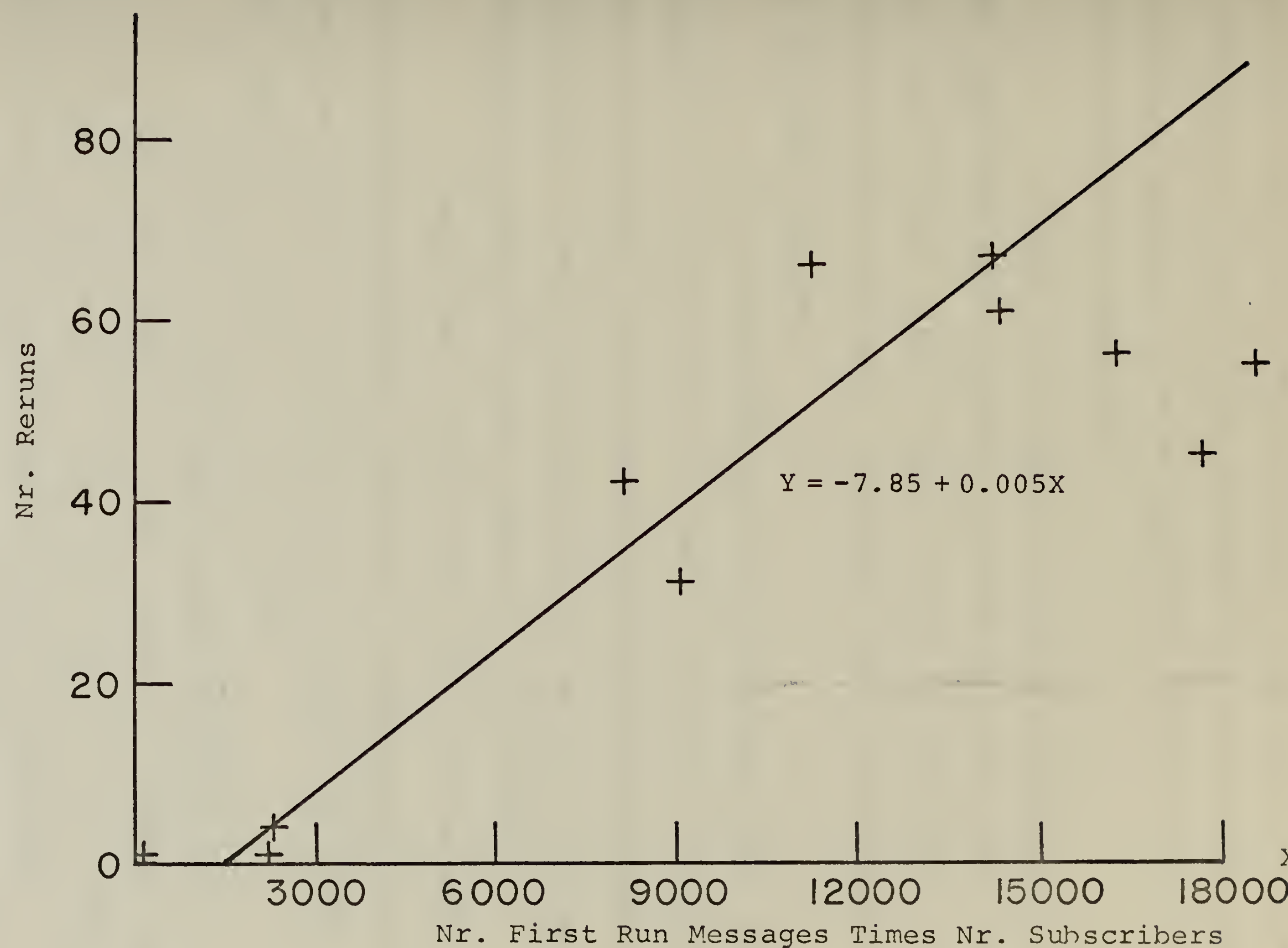


Figure 19. XRTT (Nr. First Run)(Nr. Subs) vs. Nr. Reruns.

The channel comparison mentioned above is shown in Figures 14 and 15. We note that although it appears that these regression lines have significant slope the scale of the graph causes this and one should note again that the coefficients of the control variable are nearly zero and hence there appears to be no significant difference in the way channel 3 was operated.

Figures 16 through 19 provide results for the FNSC, FRTT and XRTT channels. We see that the XRTT regression line has the largest slope of all the samples shown, however we must note that the sample size is nearly one half of the other samples.

If any conclusions are to be drawn from this analysis it would be that the number of reruns are independent of the number of first run messages and the number of subscribers. However further analysis in this area appears necessary in order to fully accept this conclusion.

Regardless of what conclusions can be made, these regression equations were used in the simulation model (described later) to mathematically simulate the effect of the rebroadcast channel on the system.

5. <u>Analysis of Time Delays in the Feedback Loop</u>

Since the model is in the form of a computer simulation it was required that each time delay of the feedback loop be analyzed and described for use in the model.

The source for this data was the broadcast service logs from NAVCOMMSTA San Francisco. These logs contained

the following information: the Date-Time-Group of the screen request message, the time the screen request arrived at the service desk, the time the screen request processing was completed, the time an answer to the screen request was sent out on the broadcast, the number of screens each request contained and the number of reruns which resulted from each request. Logs from two different months were used. One represented a high volume traffic month which was September 1971 and the other a low volume traffic month which was December 1971.

Four time distributions were analyzed. These were, the interorigination times of the screen requests, the interarrival times of the screen requests at the service desk in the NAVCOMMSTA, the delay in transmission times for the screen request messages from the originator to the NAVCOMMSTA and the delay in processing the screen request at the service desk. Additionally the distribution of the number of reruns per screen request was analyzed for use in the model.

a. Interorigination and Interarrival Distribution Analysis Results

For each of these distributions the times between successive origination and arrival times were determined and then tested for goodness of fit to the exponential distribution by using the computer analysis program. In the case of the origination time, the date-time-group of the screen request was considered as the origination time of the request. In both cases the hypothesis that these times were distributed exponentially was accepted. The results are shown

in Table X and Figure 20. This result implies that screen requests arrive at the service desk according to the Poisson Process in the same manner as first run traffic at the broadcast position. Only the interorigination distribution is used in the model.

b. Transmission Delay Distribution Analysis Results

The delay in transmission times were considered to be the time difference between the origination time and the time of arrival at the broadcast service desk. This data was tested against a right shifted exponential for goodness of fit. The right shift was used because of the observation that a message being transmitted from a ship to the NAVCOMMSTA has at least some minimum time delay. Table X shows the results for both the regular and right shifted exponential fits. The hypothesis that the data fit the right shifted exponential was accepted. Figure 21 shows the CDF graph for the September data sample. It is interesting to note that the mean transmission delay for the two sets of data were nearly the same. The sample mean for the December data was 119.6 minutes and for September it was 120.8 minutes.

c. Service Desk Delay Distribution Analysis Results

The service desk delay times were considered to be the time difference between the time of receipt or arrival of the screen request message at the service desk and the time the reply to the screen request was completed. It should be noted that the times measured here included

both the time the screen request spent in queue at the desk and the time for processing at the desk. This was purposely done in order that this distribution could be used in the model to implicitly simulate the delay resulting from other screen requests for other broadcasts and/or channels being handled at this same desk.

This data was tested against a right shifted distribution. The right shift was again used by the observation that each request however small must take some time to be processed. Table X and Figures 22 and 23 show the results of these tests. In the case of the December data the right shifted exponential was accepted as the underlying distribution while for the September data, a right shifted hyperexponential was used for the best fit.

d. Reruns per Screen Request Distribution Analysis Results

The data for this analysis represented the number of reruns per screen request for all channels previously listed for the August-September period. The data was fitted with a regular exponential distribution and the hypothesis was accepted that the reruns per screen request data is distributed exponentially. The results of the test are shown in Table X.

TABLE X. GOODNESS OF FIT RESULTS FOR FEEDBACK LOOP DISTRIBUTIONS

MO	SAMPLE SIZE	EST MEAN	PARAMETERS EST STD.DEV.	PARAMETERS EST LAMBDA	PROPORTION P	PROPORTION (1-P)	R.S. A	K-S STAT	K-S TEST RESULT	CHI-SQUARE DF	CHI-SQUARE STAT	CHI-SQUARE TEST RESULT
					INTERORIGINATION TIMES DISTRIBUTION							
DEC	85	453.5	787.88	.0022	N.A.	N.A.	0	.1645	.99	10	16.12	.95
SEP	338	121.7	154.79	.0082	N.A.	N.A.	0	.1154	REJECT	4	13.07	.99
					INTERARRIVAL TIMES DISTRIBUTION							
DEC	85	450.3	802.28	.0022	N.A.	N.A.	0	.1799	REJECT	10	24.63	.995
SEP	338	122.1	146.69	.0082	N.A.	N.A.	0	.0744	.99	8	12.38	.90
					DELAY IN TRANSMISSION TIMES DISTRIBUTION							
DEC	86	119.6	122.15	.0084	N.A.	N.A.	0	.0722	.99	4	1.13	.20
DEC	86	119.6	122.15	.0088	N.A.	N.A.	2	.0582	.99	10	6.82	.30
SEP	339	120.8	141.66	.0083	N.A.	N.A.	0	.0847	.99	8	26.01	REJECT
SEP	339	120.8	141.66	.0085	N.A.	N.A.	3	.0689	.99	7	11.50	.90
					SERVICE DESK DELAY TIMES DISTRIBUTION							
DEC	86	87.6	136.22	.0114	N.A.	N.A.	0	.1052	.99	3	7.72	.95
DEC	86	87.6	136.22	.0117	N.A.	N.A.	2	.1024	.99	3	6.71	.95
SEP	339	158.8	209.82	.0063	N.A.	N.A.	0	.1244	REJECT	10	49.04	REJECT
SEP	339	158.8	209.82	.0064	N.A.	N.A.	2	.1272	REJECT	5	50.40	REJECT
SEP	339	158.8	209.82	.0064	.2393	.7607	2	.0633	.99	6	11.59	.95
					RERUNS PER SCREEN REQUEST DISTRIBUTION							
	107	2.7	2.14	.3723	N.A.	N.A.	0	.1239	.99	9	9.65	.70

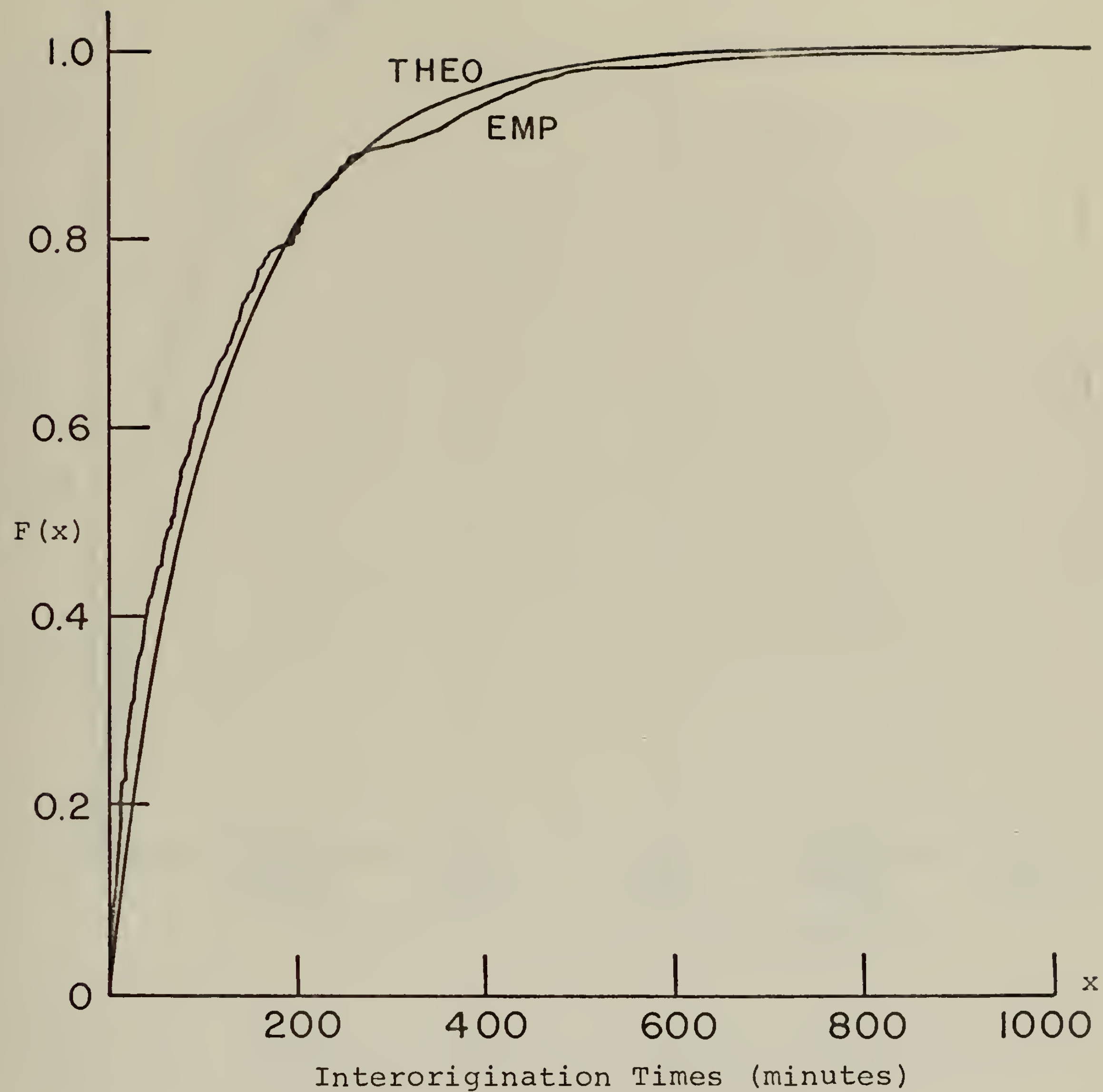


Figure 20. CDFs for Screen Request Interorigination Times (September).

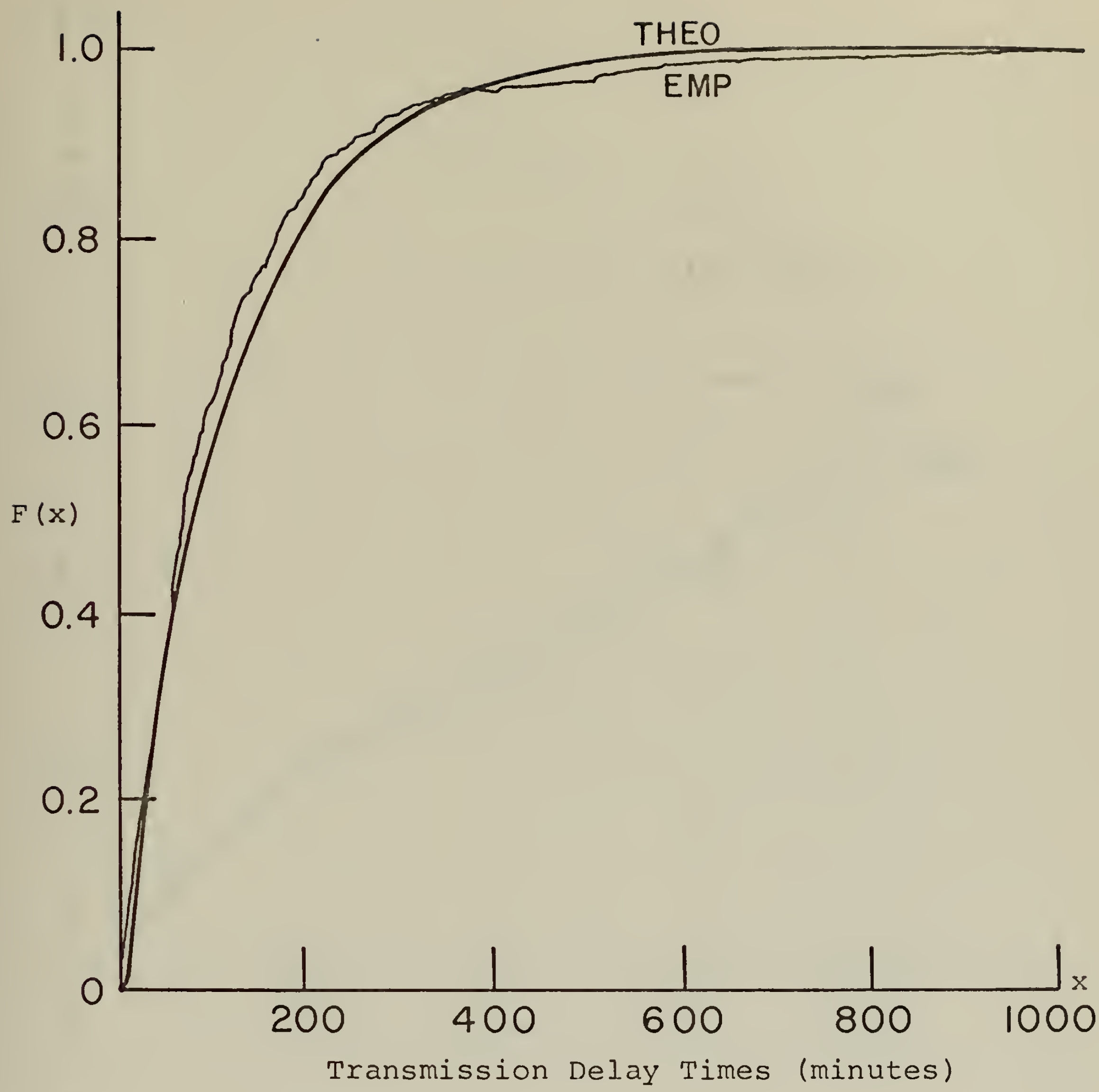


Figure 21. CDFs for Transmission Delays (September).

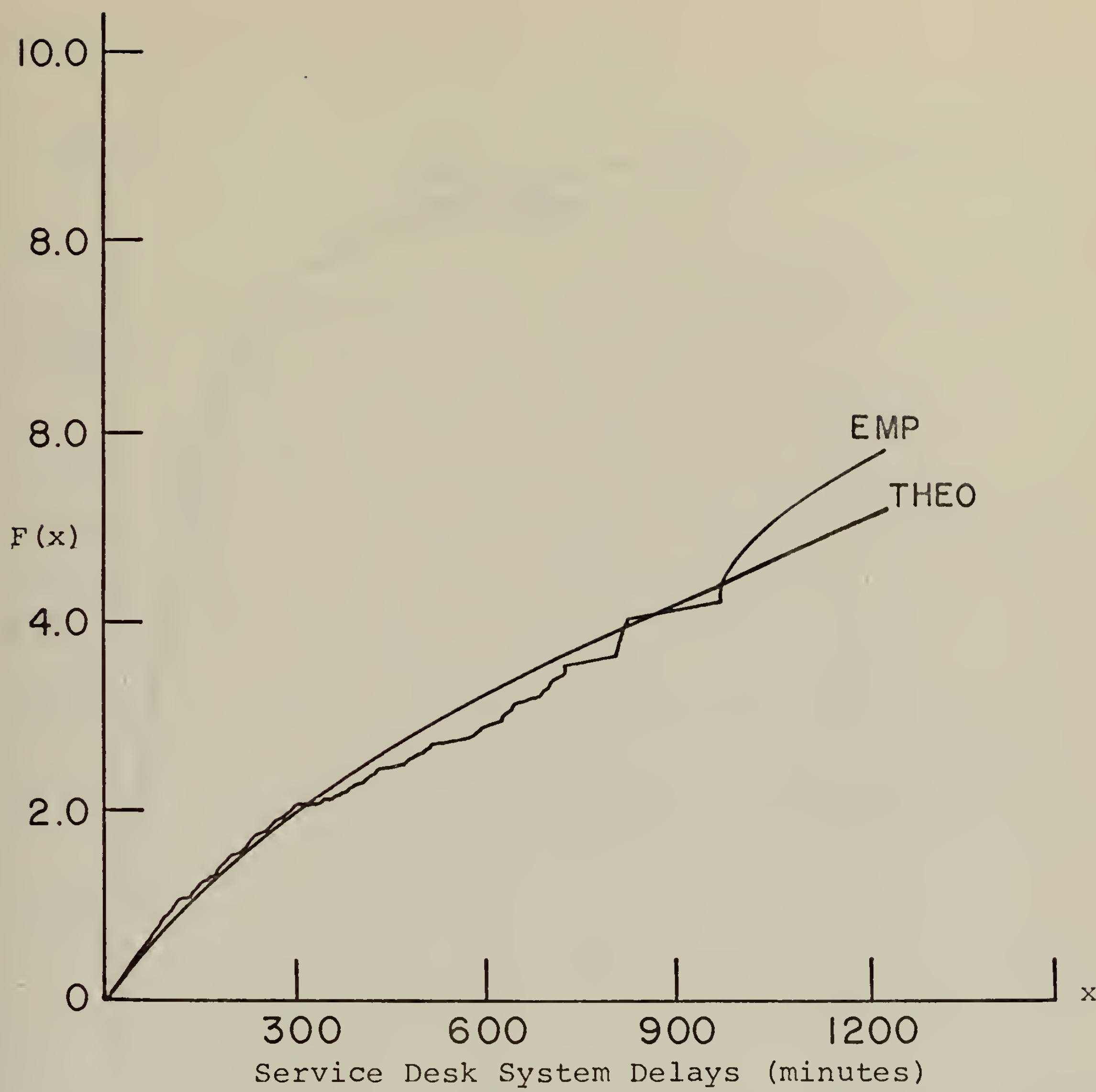


Figure 22. Log of the Tail Distribution for Service Desk System Delays (September).

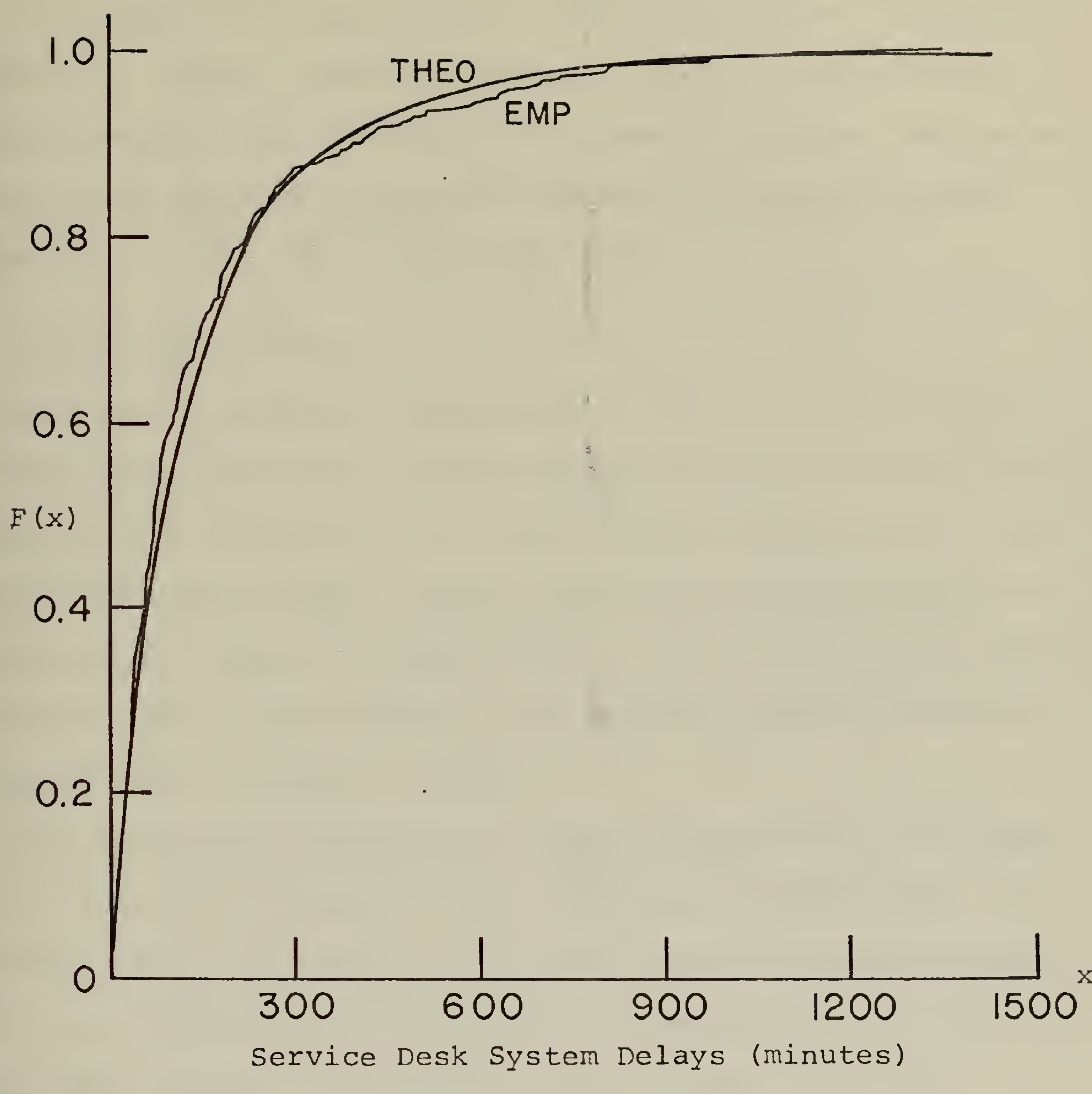


Figure 23. CDFs for SErvice Desk System Delays (September).

IV. THE MODEL

A. GENERAL DESCRIPTION

The model is in the form of a General Purpose Simulation System/360 (GPSS) computer program. GPSS is a simulation system designed for simulation of queueing systems and hence adapts very well to simulating the fleet broadcast system. References 4 and 5 fully describe GPSS.

B. MODEL CAPABILITIES

The model generates transactions which are the messages in the system and moves these messages through the model for queueing and processing in a very similar manner as the real world broadcast system. Since each of the channel pairs of the broadcast operate independently of the others, the model was designed to simulate only one channel pair of the fleet multi-channel broadcast system.

The model has essentially 3 basic components or routines which interact with each other. They are (i) the first run traffic flow for Immediate, Priority and Routine precedences, (ii) the Flash message routine with preemption, and (iii) the screen request and feedback loop routine. For the description of the model we will use "channel 1" to refer to the primary channel and "channel 2" to refer to the secondary channel.

The model is essentially very simple in its flow characteristics and has much flexibility in its use. This

flexibility is described by listing the following features which can be considered as measures of controlling the model. The user may change or specify the following control variables, distributions or methods listed.

i. The daily number of first run messages to be generated for the simulation period.

ii. The percent of each precedence of the first run messages generated.

iii. The individual message length distributions for each precedence.

iv. The mean message length for each precedence.

v. The diurnal message arrival function.

vi. The number of subscribers.

vii. The backlog levels by precedence to be allowed before opening and closing channel 2 for transmitting first run traffic.

viii. Allow Flash messages to preempt other messages using either the Preempt Rerun method or the Preempt Resume method.

ix. The mean transmission delay for screen requests or the distribution of this delay.

x. The percent of screen request to be processed by the Broadcast Control Station and the percent to be processed at other NAVCOMMSTAs.

xi. The service desk processing delay distribution.

xii. The mean service desk delay for the BCS and/or the other NAVCOMMSTAs.

xiii. The mean number of reruns per screen request or the distribution.

xiv. The mean transmission delay for reruns to reach the BCS after being processed by the other NAVCOMMSTAs.

xv. The control of whether rerun messages processed by the BCS are allowed to go to the head of the line of first run messages waiting in queue.

C. DESCRIPTION OF THE MESSAGE FLOW IN THE MODEL

The flow charts shown in Figures 24 through 27 provide a simplified picture of the message flow through the model. First consider the traffic flow for Immediate, Priority and Routine precedences. These messages plus Flash are generated according to an exponential distribution with a mean inter-arrival rate specified and a specified diurnal function. After a message is generated its precedence is determined by a percentage function specified. After the precedence is assigned the model routes the messages by precedence to be assigned their appropriate message lengths from functions specified and then puts the messages in queue by precedence. At this point in the model the Flash messages are handled in a slightly different manner than the other messages. This is described below. The precedences or priority numbers assigned by the model, depending on the precedence assignment function specified, are as follows (listed from lowest to highest with designations in parentheses)

1-Routine First Run (R)
2-Routine Rerun (RRR)
3-Priority First Run (P)
4-Priority Rerun (PRR)
5-Immediate First Run (O)
6-Immediate Rerun (ORR)
7-Flash (First Run and Rerun) (z).

The model chooses the highest precedence and in order of arrival within precedences when advancing transactions through the model. Thus messages waiting in queue are chosen by highest precedence and on a first in first out basis for routing to the transmission channels. We note that when priority numbers 2, 4 and 6 are assigned to reruns processed

by the BCS, these messages will be transmitted before their first run counterparts. Hence this simulates allowing the reruns to be put at the head of the line.

When a message is routed for transmission the model checks to determine the number of backlog by precedence and compares it to a specified value of allowed backlog for a given precedence. If the backlog for any precedence exceeds the allowed backlog the model will start a 30 minute timer (or a time specified) which represents the notification to the subscribers of the intent to activate channel 2 for first run traffic. At the end of the 30 minute period channel 2 is opened for first run traffic. Whether or not the timer is activated the message proceeds to channel 1 for transmission. Although the flow chart best illustrates this test as occurring sequentially between the time the message departs the queue and before transmission, this is not the way it occurs in the model. Actually all the above described assignments and tests are made at the instant in simulation time when the message is generated. That is, when the message is generated even though it is part of the queue, the message proceeds through the model until it is refused entry to some GPSS block (program statement). Thus the messages proceed through the GPSS model to the BUFFER block and the main GATE 1 before being stopped. For statistical purposes the messages do not depart from their respective queues until they pass through the DEPART block and this occurs only when a channel is available and the message is allowed to SEIZE a channel in order to be transmitted.

The message is held in the transmission channel (ADVANCE block) for a period of time equal to its assigned message length. When the transmission is complete the message releases the channel and is terminated and removed from the system. The main GATE 1 closes when a message SEIZEs a channel and opens when the message RELEASEs a channel.

If channel 2 has been activated for first run traffic, then the model processes the messages through channel 2 in the same manner as in the primary channel. Messages waiting for transmission are selected in the precedence order described above and each time a channel is finished with a transmission, or is available, the model will move the available message to the appropriate channel. When a message is processed by channel 2, the backlog of the Priority and Routine precedences are checked against a specified value to determine if channel 2 should be closed. If channel 2 can be closed this will activate a timer which runs for the duration of the message length of the message in channel 2 and then closes channel 2 to any further first run traffic.

It is noted with emphasis that the secondary channel in the model does not process messages when it is considered as being used for rebroadcast of the primary channel traffic. In the model this feature is handled through a mathematical relationship which will be more fully described below.

The next part of the model to be described is the Flash message routine. This is described separately to point out that although the Flash messages are generated as a part of

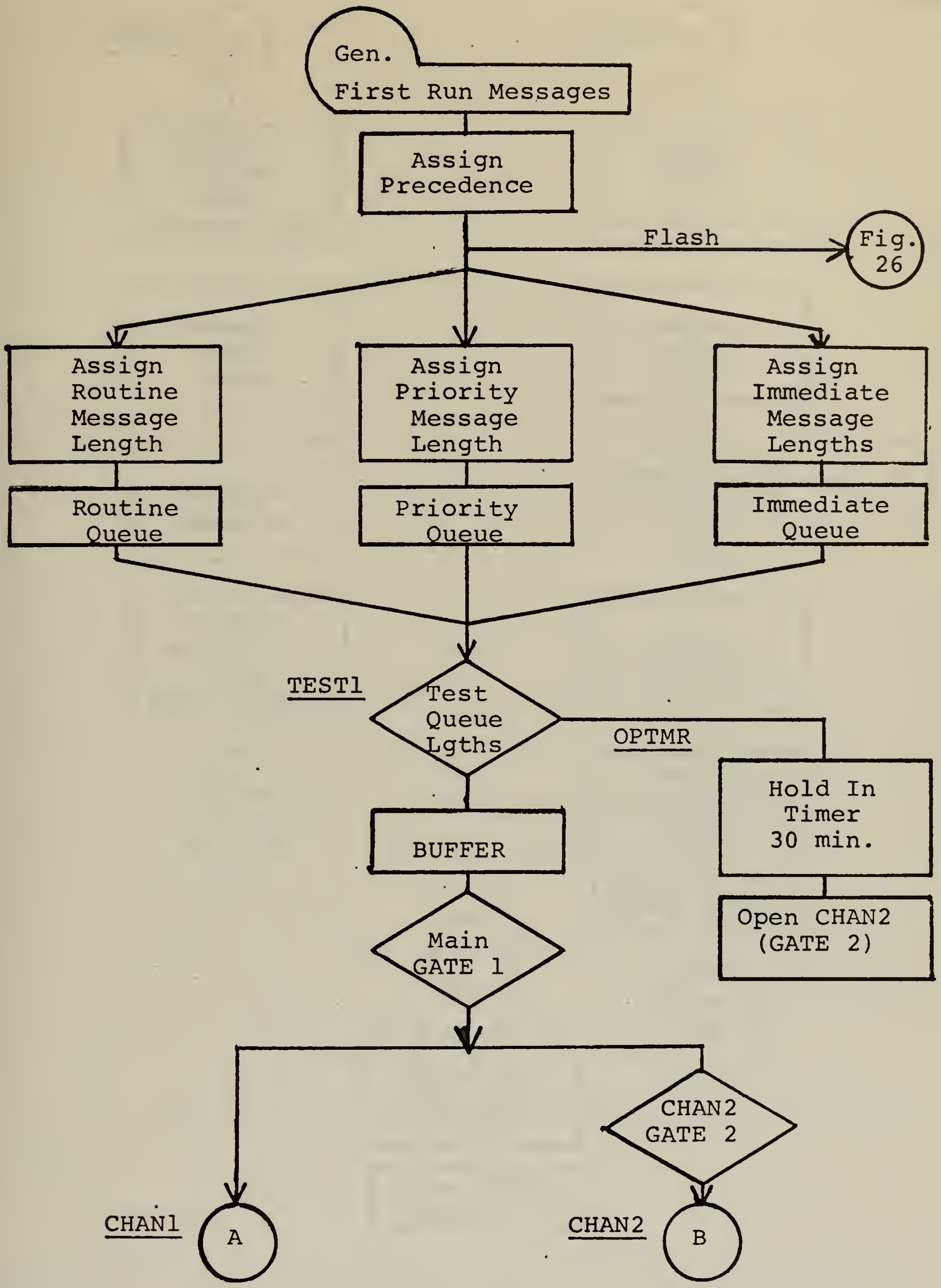
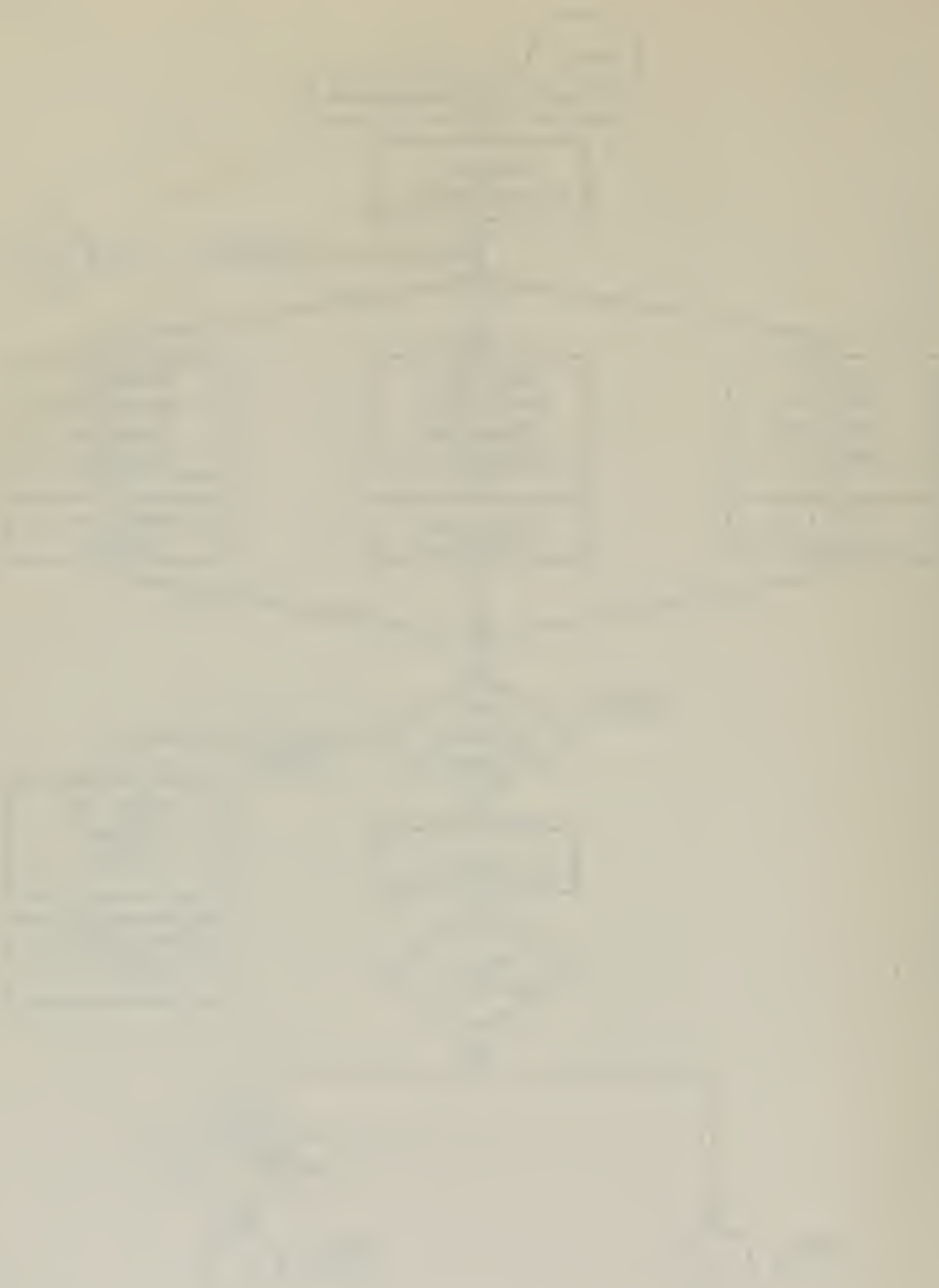


Figure 24. First Run Traffic Flow in the Model.



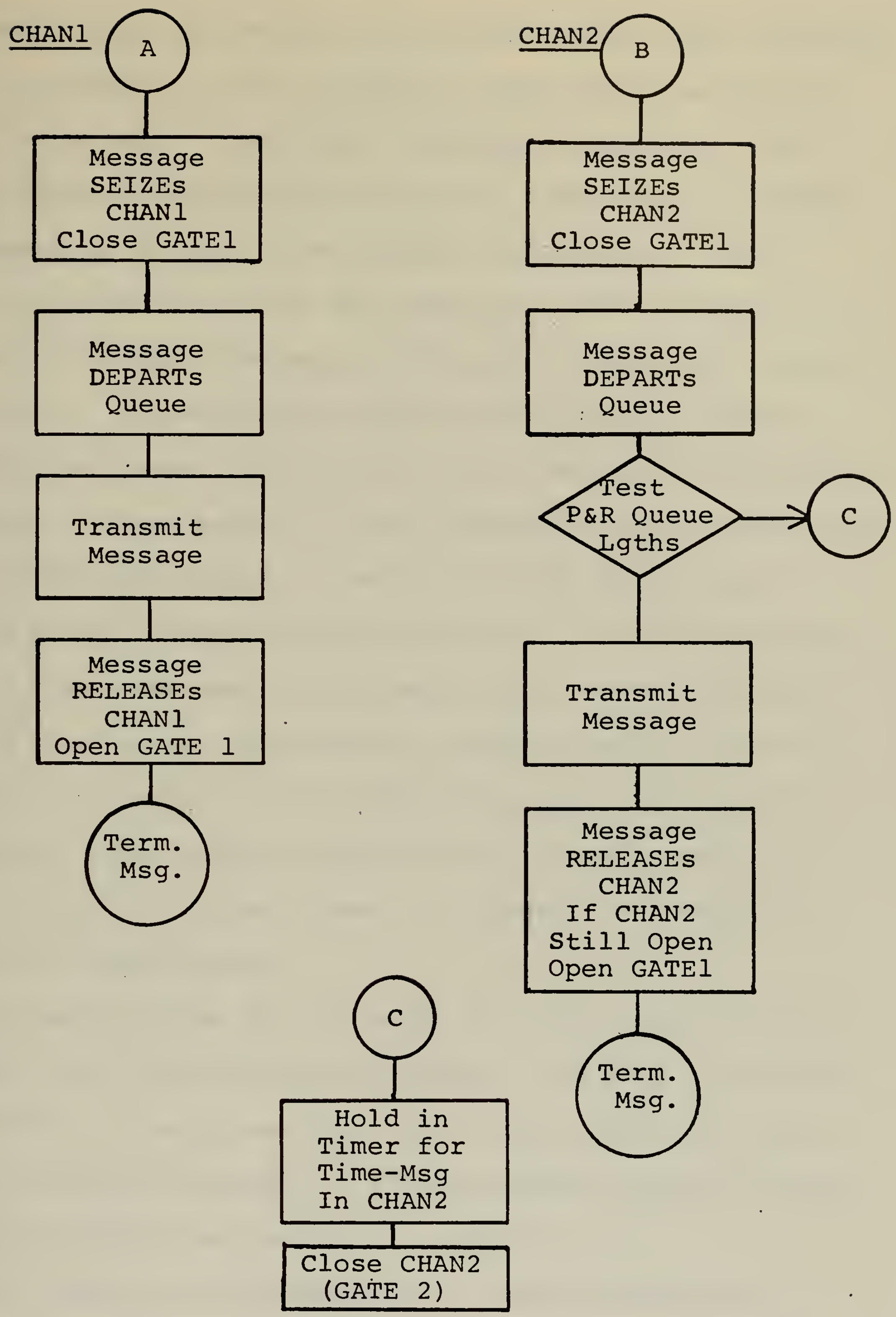


Figure 25. First Run Traffic Flow in the Model (Continued).

the overall first run traffic described above, these messages follow a different route through the model because they are allowed to preempt other lower precedence messages. When a Flash message arrives in the system it immediately preempts any message in channel 1 and begins transmission. Just before transmission and in the simulation time instant of generation the Flash message is assigned its message length along with a 25 word header and then the entire length is multiplied by three. This part of the simulation represents two things. First before a Flash message starts transmission on the broadcast channel a heading is sent which reads, "ZUJ FOR FLASH---------ZUJ FOR FLASH" etc., and means Stand By for a Flash Message. This header also causes attention bells to ring on the subscriber's teletype thereby drawing attention to the fact that a Flash message is about to be transmitted. The second item is that a Flash message is always transmitted three times in succession to ensure receipt by the subscribers.

The Flash routine also provides for the situation when more than one Flash message may arrive. In this situation if channel 2 is being used for first run traffic and channel 1 is already processing a Flash message then the second Flash will preempt any message in channel 2.

When a message is preempted by a Flash message, the preempted message is handled by the model in such a manner that when the Flash finishes transmission, the preempted message will be run again from its beginning, if the model

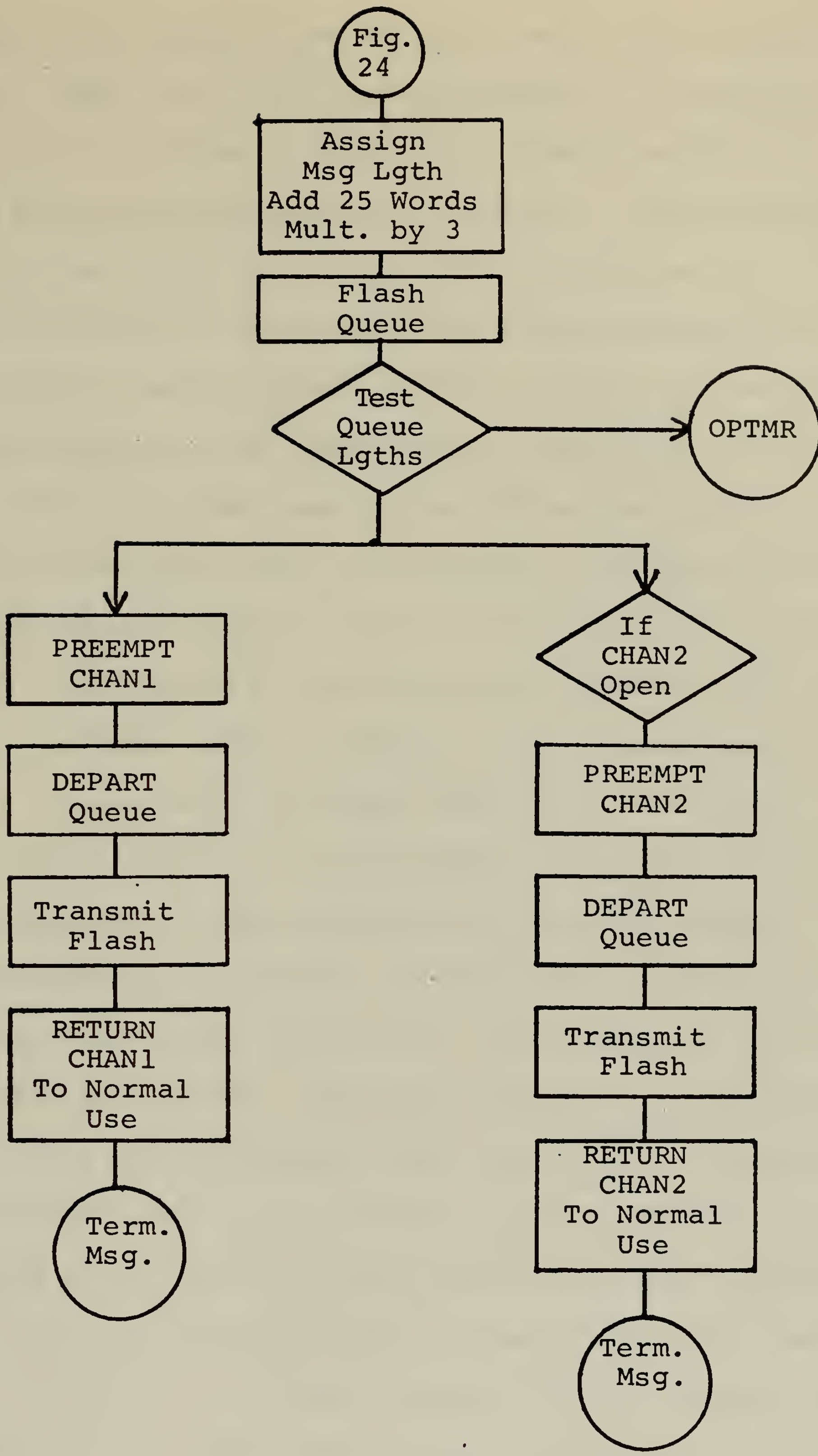


Figure 26. Flash Message Routine, with Preemption.

is being operated in the Preempt Rerun mode. If channel 2 is open for first run traffic and a message is preempted in channel 1 and if channel 2 becomes available before the Flash has finished transmission in channel 1 the preempted message will be routed and transmitted on channel 2.

The third part of the model is the Screen Request and Feedback Loop of the broadcast system. Screen requests are generated according to an exponential interorigination distribution with specified mean value. When the screen requests are generated they are assigned a transmission time from a right shifted exponential distribution with a given mean time. This holds the request in an ADVANCE block for this period of time before allowing it to proceed through the model. It is noted that more than one request can be in this ADVANCE block at one time thus simulating any number of screen requests in transmission to the NAVCOMMSTA. The model then randomly determines according to a percent specified whether the screen request will be handled by the BCS or by another NAVCOMMSTA. Next the request is assigned a service desk system processing time and is held in an ADVANCE block to simulate the time a screen request spends in the service desk queue and on the service desk being processed. This time delay distribution with its specified mean represents the competition a screen request for the channel pair being simulated has with other screen requests for other broadcast channel pairs or other broadcasts. When the request has finished processing and is ready to proceed,

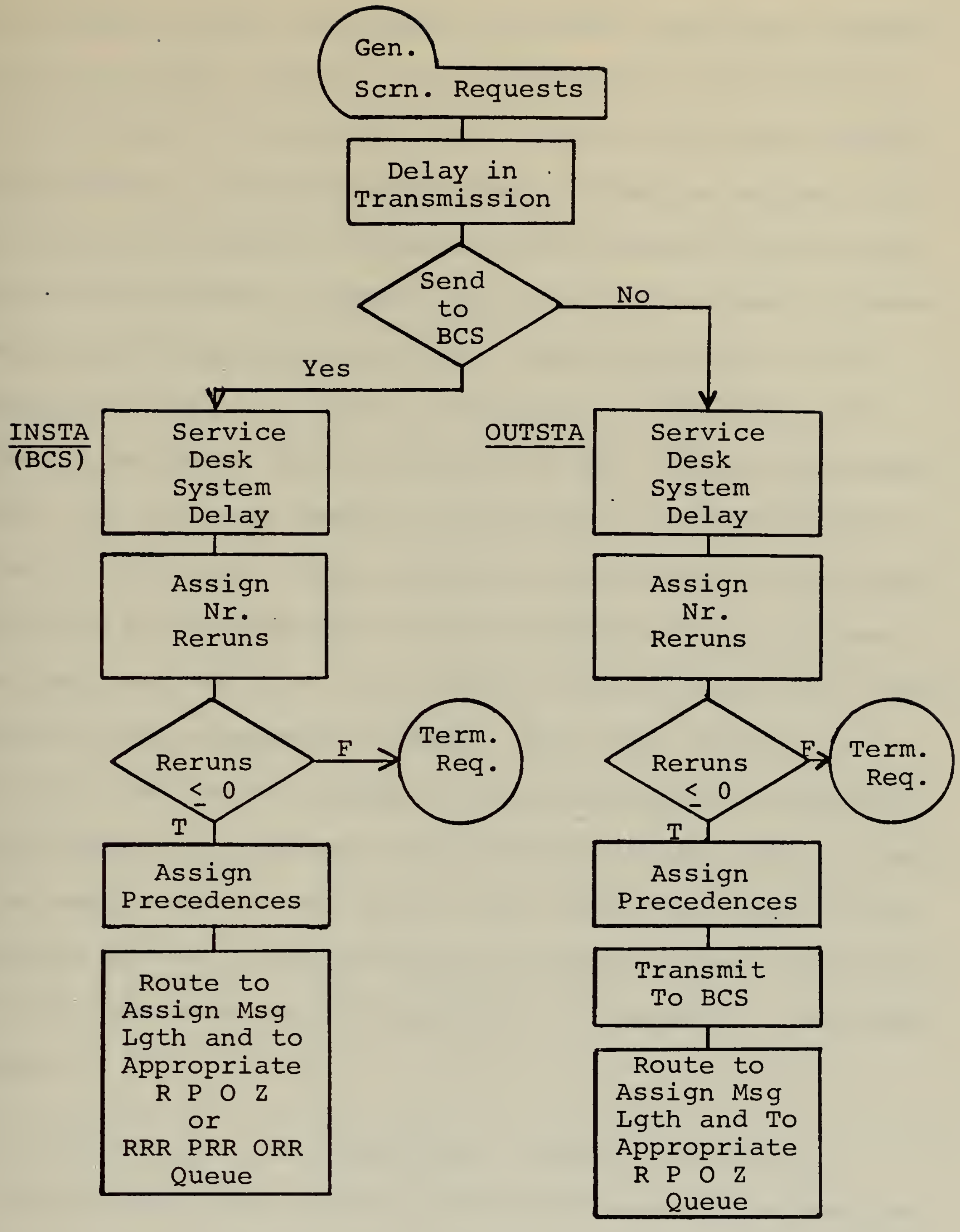


Figure 27. Screen Request and Feedback Loop.

it is then assigned the number of reruns that have resulted from this screen request from an exponential distribution. If the number of reruns is equal to zero the screen request transaction is terminated and removed from the system. If the number of reruns is greater than or equal to one, then each rerun becomes a message itself and is assigned a precedence and an appropriate message length and sent to its appropriate queue to await transmission. The option of allowing reruns to go to the head of the line was described above. If a screen request was processed by a NAVCOMMSTA other than the BCS, those reruns are assigned a transmission time from the transmission delay distribution with a specified mean and held for that period in an ADVANCE block before joining their respective queues. This time simulates the time it takes for the reruns to be transmitted via AUTODIN to the BCS. It is noted that in this case the reruns cannot be allowed to go to the head of the line since these rerun messages arrive at the broadcast position in the same manner as first run messages and therefore are handled in the same manner.

D. THE MODEL AND THE REBROADCAST CHANNEL SIMULATION

As was mentioned above, this model does not rebroadcast first run messages as though they were being sent on a 1 hour delay rebroadcast channel. The secondary channel in the model is used solely for processing first run messages and when it is not doing so it is not used. The effect of the use or non-availability of the rebroadcast channel to

the subscribers is simulated through the control of the mean interorigination times of the screens requests. This is done by using a representative regression equation of (Nr. First Run)(Nr. Subscribers) vs. Nr. Screens for the channel pair being simulated. Thus by specifying the number of first run messages and the number of subscribers for the simulation period, the model determines the number of screens that will be handled. Then by further specifying the average number of screens per request the model determines the number of screen requests to be generated and with this information the model calculates the mean interorigination time by dividing the number of requests into the simulation time period. In the real world system it is assumed that when the rebroadcast channel is being used, that the number of screens requests is less than when the secondary channel is not being used for rebroadcast of first run traffic. Then if this assumption is in fact true the analyst need only decrease the mean interorigination time for the screen requests when the secondary channel is open for first run traffic. This therefore simulates a higher number of screen requests being generated and handled at the service desk and thus more reruns are generated. This is done in the model by one of two ways. The regression equation used can be changed when channel 2 is open or simply the number of screens per request can be changed in order to effect the increase of screen requests. Note that this change in the mean interorigination time is made at

the time that the secondary channel is opened or closed for first run traffic. Thus we can observe how the increase in the number of reruns affect the system and since the time delays are built in the feedback loop we can also observe any surge in reruns which may occur after the secondary channel was opened for first run traffic.

E. VERIFICATION OF THE MODEL

As the model was built, each routine added was run separately to verify that the logic design was correct and the transaction flow was being performed correctly. The means and variances of interarrival times and message lengths, etc., generated by the model using random number generators and the specified functions, were checked for accuracy. Appropriate modifiers (explained in model documentation) were chosen to ensure that the model generated the function values with a reasonable accuracy for the mean values desired.

One important verification was made by running the model for the M/M/1 and M/M/2 queueing systems. That is, the model was run without the feedback loop and the Flash preemption routine and with exponential (M) interarrival and service times for one server (only channel 1 open) and two servers (both channels open) [6,7]. The results of these model runs were compared to analytical calculations for the average server utilization and the average queue length and waiting times. These comparisons showed that the model was very accurate.

The model was also verified in its final form by using data obtained from OEG which was gathered during ROPEVAL 3-71 [1]. This data represented the actual hourly number of arrivals and backlogs observed during the period of 13-16 September on channel 1 (FASW). For the comparison runs with the model, parameters of the model were set at values that were observed during this time period. The parameters which were not varied for the comparison runs and for later described runs are shown in Table XI below.

The observed traffic loads, number of subscribers number of screen requests and number of reruns are shown in Table XII.

TABLE XI

MODEL PARAMETERS HELD CONSTANT

	Flash	Immediate	Priority	Routine
Msg Lgth Mean	89.2	245.3	257.3	182.6
% of First Run	1.5	22.5	35.7	40.3
% of Reruns	1.5	22.5	35.7	40.3
Allowed Backlog for				
Opening CHAN2	3	10	50	110
Closing CHAN2	-	-	1	2

TABLE XII

FASW 13-16 SEP OBSERVED TRAFFIC LOADS

Day	Nr. First Run	Nr. Subscribers	Nr. Screen Requests	Nr. Msgs Rerun
13 SEP	422	38	6	6
14 SEP	668	40	8	4
15 SEP	598	40	13	10
16 SEP	480	33	6	36
Totals	2168		33	56

To simulate the daily and hourly fluctuations of traffic arrivals during the period 13-16 September the model used the number of first run messages shown in Table XII above and the "diurnal" function shown in Figure 28 below. The specified dirunal function allows the model to determine the proportion of a day's first run traffic that will arrive or be generated each hour of the simulation run. Another function in the model specifies the number of subscribers copying the channel pair each day, the numbers used are shown in Table XII above. The percentage of first run messages and reruns that were assigned each precedence are shown in Table XI above. These percentages were the observed aggregate percentages for the 13-16 September period being simulated.

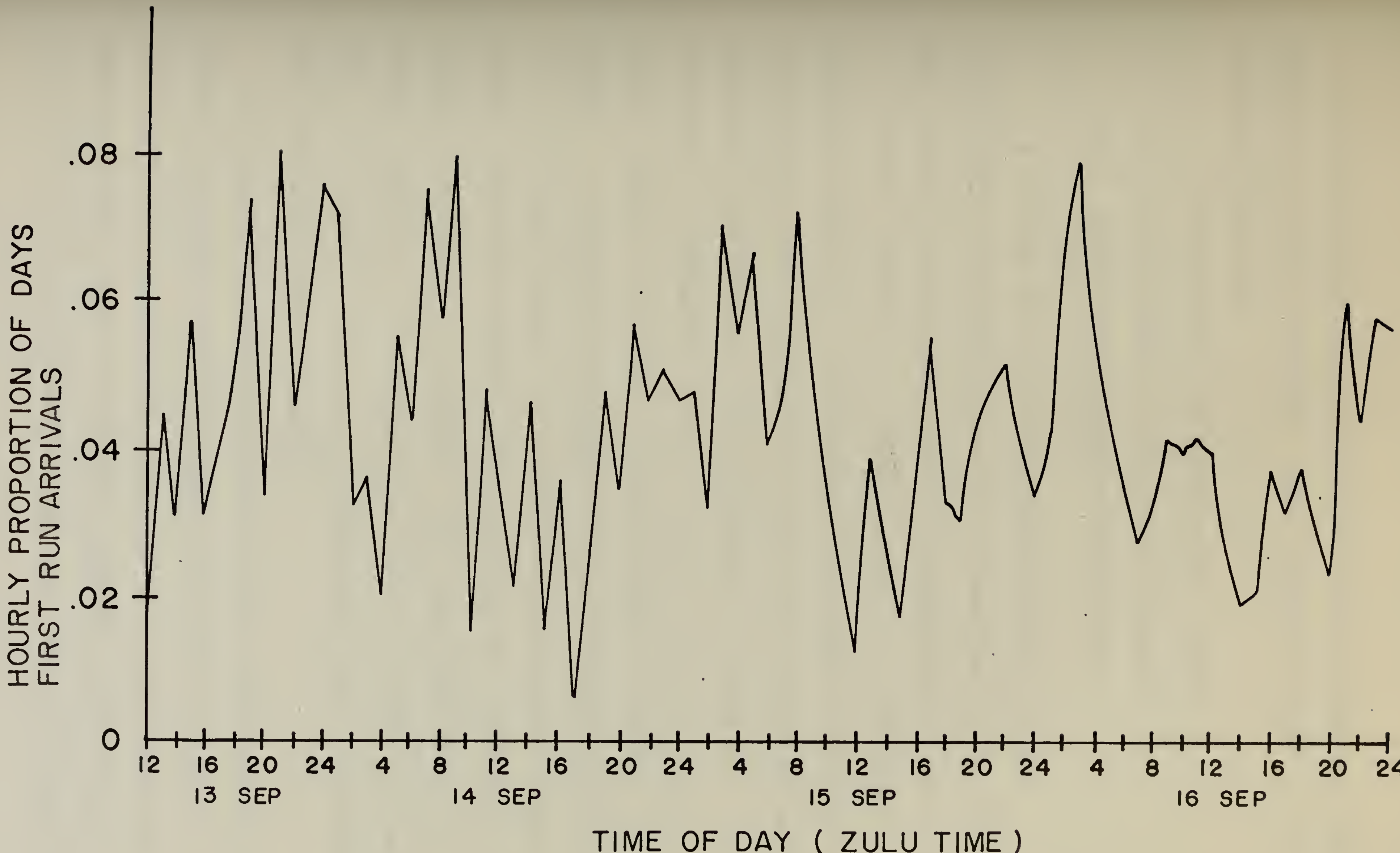


Figure 28. Diurnal Function for 13-16 SEP. FASW Message Arrivals.

In the simulation the Broadcast Control Station (BCS) handled all screen requests. The parameters used for the feedback loop were:

i. Mean Number of Screens per Request = 8

ii. Mean Number of Reruns per Request = 1

iii. Mean Screen Request Transmission Delay = 120 mins.

iv. Mean Service Desk System Delay = 75 min.

To determine the number of screens (messages to be screened) that would be handled each day the regression equation, $Y = 44.36 + .00065(X)$, was used, where X is the number of messages transmitted the previous day times the number of subscribers. This equation is taken from the above described regression analysis for FASW (channel 1) during the 25 August-17 September period. Recall that during this period channel 2 was used for rebroadcast of channel 1 traffic. The model determines the mean interorigination time for screen requests by first calculating the number of screens and then dividing that number by the specified mean number of screens per request. This gives the number of screen requests. By dividing the number of screen requests into 1440 minutes the result is the daily mean interorigination time for screen requests.

To compare the model results to those actually observed during the period 13-16 September the model was run in two different forms. First the model was run with empirical message length functions and with empirical functions for the service desk system delays and the number of reruns per

screen. Secondly, the model was run with theoretical functions for all distributions except Flash message lengths. The Flash message length distribution was left as an empirical distribution since the size of sample tested did not allow us to conclude the exact nature of its distribution.

The results of these comparison runs are shown in Table XIII and Figure 29 below. By comparing the average queue lengths and the average wait in queue we see that the model is conservative. We also note that the model with theoretical functions is more conservative than the run with empirical functions. In comparing the backlog curves in Figure 29 we note that the model tracks well. That is, the model shows peak backlogs build ups and declines at nearly the same times as were observed from the actual data.

It should be pointed out that we cannot say that this comparison validates the model since each simulation run and the actual observations for this period are observations of a random process. Even if the actual data could be observed again in the very same circumstances as the period of 13-16 September the results would not be the same, nor would simulation model runs with different seeds for the random number generators be the same.

F. MODEL SIMULATION RUNS AND RESULTS

1. Description of the Simulation Runs

The model with theoretical functions was used for this experiment since it was determined above that it was

TABLE XIII. MODEL VERIFICATION RESULTS

NAME	TOTAL NR 1STRUN	TOTAL NR RERUN	TOTAL NR SCRN REQ	AVE CHANNEL USE 1	AVE CHANNEL USE 2	PREC	AVE QUEUE TIME	AVE QUEUE LGTH	MAX QUEUE LGTH	STD DEV
ACTUAL	2168	56	33	UNKNOWN		R	150.9	22.94	86	
						P	13.3	1.78	15	
						O	2.5	.21	2	
						ALL	66.4	24.95	93	25.11
SIMULATED RUN WITH EMP FUNCTS	2155	74	31	.867	CLOSED	R	251.8	36.82	129	
						RRR	56.4	.29	6	
						P	24.0	3.21	29	
						PRR	7.1	.03	4	
						O	4.6	.41	9	
						ORR	3.6	.01	3	
						ALL	109.5	41.01	138	38.88
SIMULATED RUN WITH THEO FUNCTS	2153	81	25	.903	CLOSED	R	397.0	58.16	159	
						RRR	144.6	.80	11	
						P	23.5	3.09	34	
						PRR	18.8	.13	10	
						O	4.2	.38	8	
						ORR	3.5	.01	3	
						ALL	167.7	62.69	175	51.19

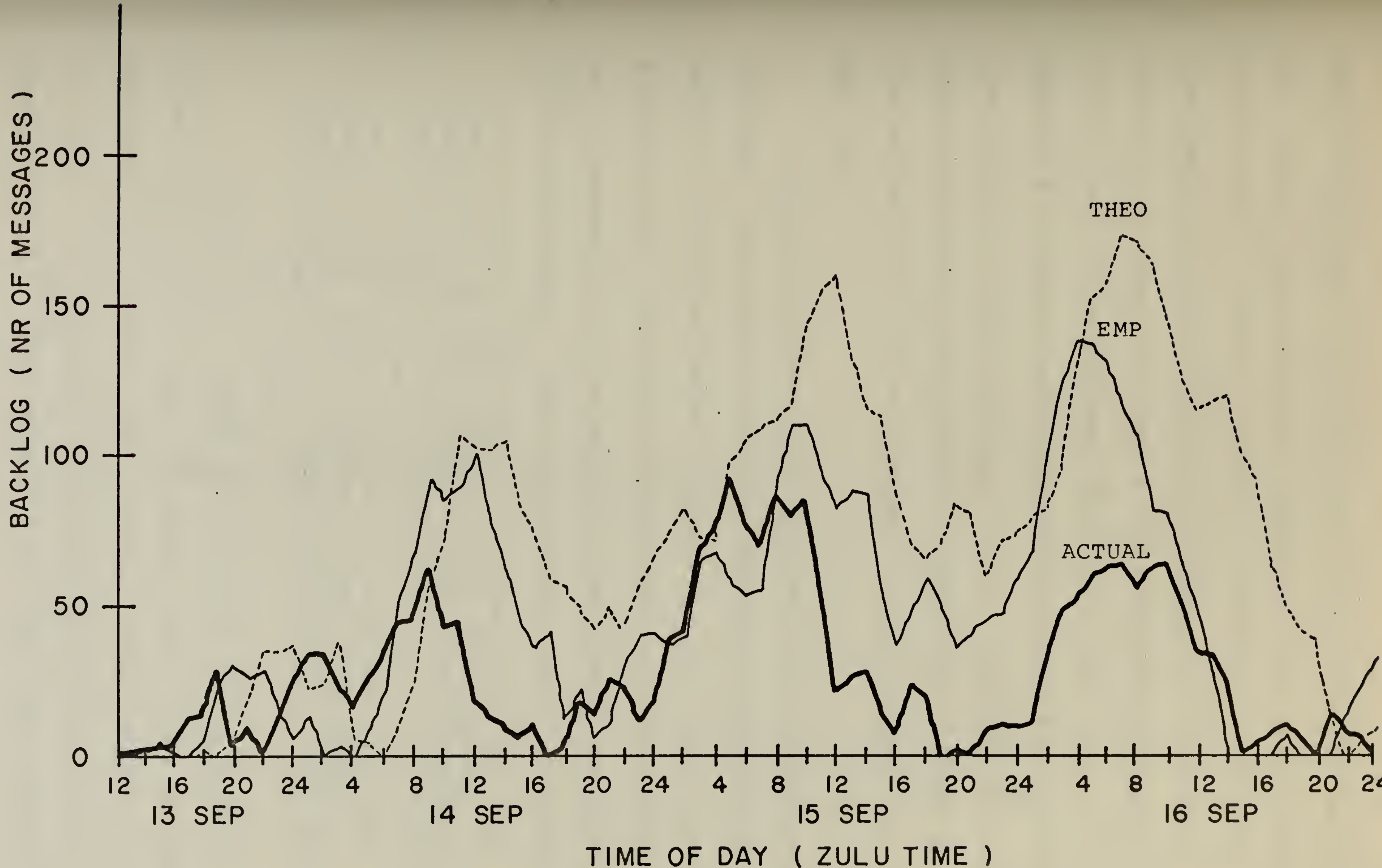


Figure 29. Model Simulation and Actual Total Backlogs on FASW 13-16 SEP.

more conservative than the model with empirical functions. The channel pair system was simulated under three different situations, i) channel 2 closed to first run traffic but considered as being used for rebroadcast of channel 1 traffic, ii) channels 1 and 2 both transmitting first run traffic and the rebroadcast facility is not used, and iii) channel 2 is opened and closed during the run by the timers when specified backlogs were exceeded. Additionally the above situations were run where reruns were allowed to go to the head of the queue as opposed to going to the back of the line.

Eight simulation runs were made with these configurations. Four simulation runs were made representing the period of 13-16 September and the other four runs represented a hypothetical four days in which the first run traffic loads were increased by 200 messages per day over those observed in Table XII above. The runs made are listed as follows:

- Run 1. 13-16 SEP. Channel 2 Closed for First Run
- Run 2. 13-16 SEP. Channel 2 Open Whole Period
- Run 3. 13-16 SEP. Channel 2 Opened and Closed by Timers
- Run 4. Same as Run 2 with Reruns going to the back of the line
- Run 5. High Loads, Channel 2 Closed for First Run
- Run 6. High Loads, Channel 2 Open Whole Period
- Run 7. High Loads, Channel 2 Opened and Closed by Timers
- Run 8. Same as Run 7 with Reruns going to the Head of the Line.

In runs 1-3, reruns were allowed to go to the head of the queue and for runs 5-7 reruns were put at the end of the queue. All of the runs used the dirunal function shown in Figure 28 to determine the hourly first run arrivals. In runs 2-3 and 6-7, when channel 2 was open, the number of

screens were calculated by using a different regression equation and mean number of screens per request such that the model would simulate a higher number reruns. For runs 1-4 the mean service desk system delay set at 75 minutes while for runs 5-8 it was set at 158 minutes (see Table X).

The allowed backlog levels shown in Table XI for opening channel 2 in simulation runs 4 and 7 were chosen based on the Broadcast Speed of Service Criteria shown in Table I. By using a familiar queueing theory equation, $L = \lambda W$, where L is the average queue length, W is the average wait in queue and λ is message arrival rate, one can determine the approximate backlog levels allowed before the Speed of Service Criteria are exceeded [6,7]. We note that this equation relates averages over a period of time. Therefore the maximum allowed routine queue length, which is usually the largest queue, was determined by using this equation and the arrival rate of routine messages observed during the 13-16 September period. The other allowed backlogs by precedence were chosen somewhat arbitrarily but such that the allowed backlog would not exceed on the average, the Broadcast Speed of Service Criteria.

2. The Results of the Simulation Runs

The results of these eight simulation runs are shown in Tables XIV and XV and Figures 30-32. In comparing the average queue lengths, average wait in queue and the maximum backlog observed plus the backlog curves the result of the simulation is obvious. The system configuration where both

TABLE XIV. MODEL SIMULATION RESULTS FOR 13-16 SEP FASW TRAFFIC LOADS

RUN NAME	TOTAL NR 1STRUN	TOTAL NR RERUN	TOTAL NR SCRN REQ	AVE CHANNEL USE 1	AVE CHANNEL USE 2	PREC	AVE QUEUE TIME	AVE QUEUE LGTH	MAX QUEUE LGTH	STD DEV
13-16 SEP CHANNEL 2 CLOSED (RUN 1)	2153	81	25	.903	CLOSED	R	397.0	58.16	159	
						RRR	144.6	.80	11	
						P	23.5	3.09	34	
						PRR	18.8	.13	10	
						O	4.2	.38	8	
						ORR	3.5	.01	3	
						ALL	167.7	62.69	175	51.19
13-16 SEP CHANNEL 2 OPEN WHOLE PERIOD (RUN 2)	2155	71	22	.527	.374	R	2.7	.40	10	
						RRR	14.0	.06	8	
						P	1.1	.15	7	
						PRR	6.3	.04	9	
						O	.7	.07	5	
						ORR	3.4	.01	3	
						ALL	1.9	.71	12	2.00
13-16 SEP CHANNEL 2 OPEN AND CLOSED BY TIMERS (RUN 3)	2148	148	36	.837	.087	R	208.3	30.49	117	
						RRR	90.3	.94	13	
						P	21.8	2.88	38	
						PRR	22.4	.21	13	
						O	4.5	.40	11	
						ORR	4.8	.03	6	
						ALL	94.6	35.29	119	35.89
SAME AS RUN 2 WITH RERUNS TO END OF LINE (RUN 4)	2152	85	28	.904	CLOSED	R	391.5	59.61	170	
						P	22.7	3.12	34	
						O	4.0	.37	8	
						ALL	169.4	63.29	176	51.54

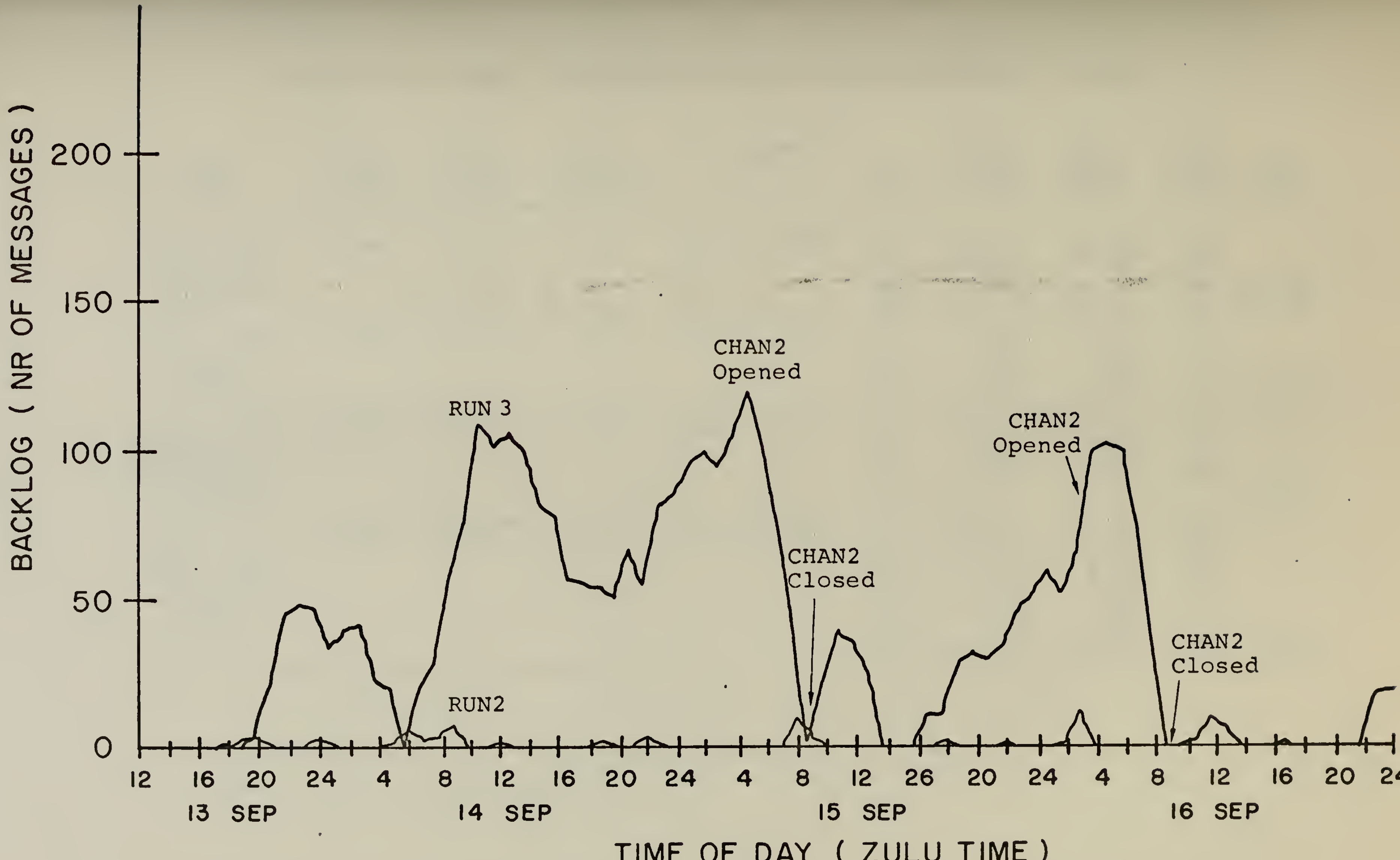


Figure 30. Total Backlogs for Simulation Runs 2 and 3 (CHAN2 Open and CHAN2 Open/Close) for FASW Traffic, 13-16 SEP.

TABLE XV. MODEL SIMULATION RESULTS FOR HIGH TRAFFIC LOADS

RUN NAME	TOTAL NR 1STRUN	TOTAL NR RERUN	TOTAL NR SCRN REQ	AVE CHANNEL USE 1	AVE CHANNEL USE 2	PREC	AVE QUEUE TIME	AVE QUEUE LGTH	MAX QUEUE LGTH	STD DEV
HIGH LOADS	2994	132	21	.958	CLOSED	R	2155.8	459.22	976	
CHANNEL 2						P	120.3	23.37	107	
CLOSED						O	5.7	.73	13	
(RUN 5)						ALL	939.7	488.44	982	352.24
HIGH LOADS	2983	455	93	.755	.659	R	48.0	11.34	93	
CHANNEL 2						P	6.0	1.27	17	
OPEN						O	1.6	.23	9	
(RUN 6)						ALL	25.2	13.07	87	21.27
HIGH LOADS	2989	156	31	.930	.337	R	239.1	51.30	197	
CHANNEL 2						P	20.1	3.93	37	
OPEN/CLOSE						O	3.6	.46	14	
BY TIMERS						ALL	108.3	56.18	200	56.17
(RUN 7)										
SAME AS	2994	189	36	.927	.350	R	280.9	56.43	182	
RUN 7 WITH						RRR	83.4	1.33	28	
RERUNS TO						P	22.5	4.24	35	
HEAD OF						PRR	14.0	.13	7	
LINE						O	3.8	.47	9	
(RUN 8)						ORR	3.9	.03	5	
						ALL	121.5	63.13	189	57.87

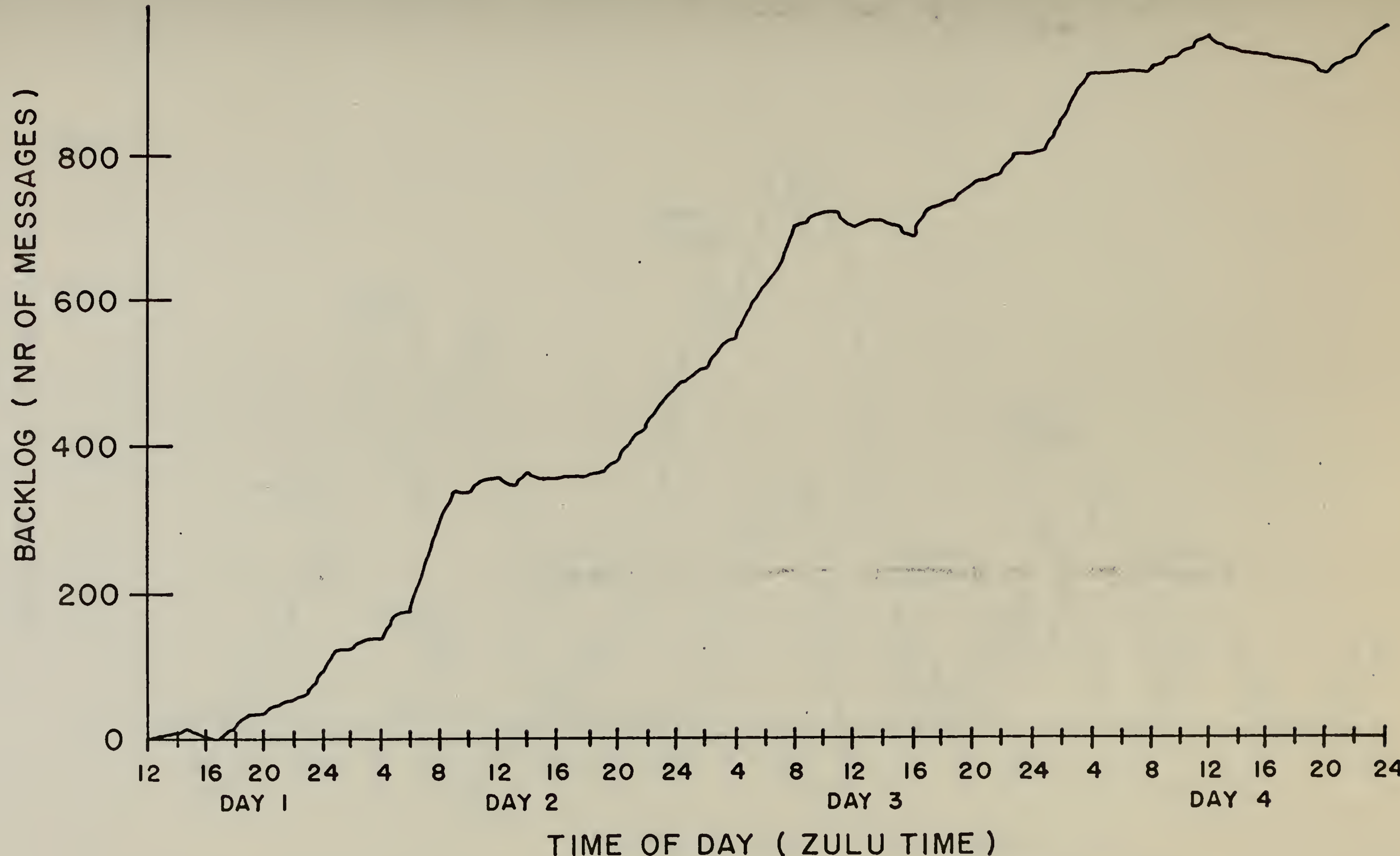


Figure 31. Total Backlogs for Simulation of High Traffic Loads (CHAN2 Closed).

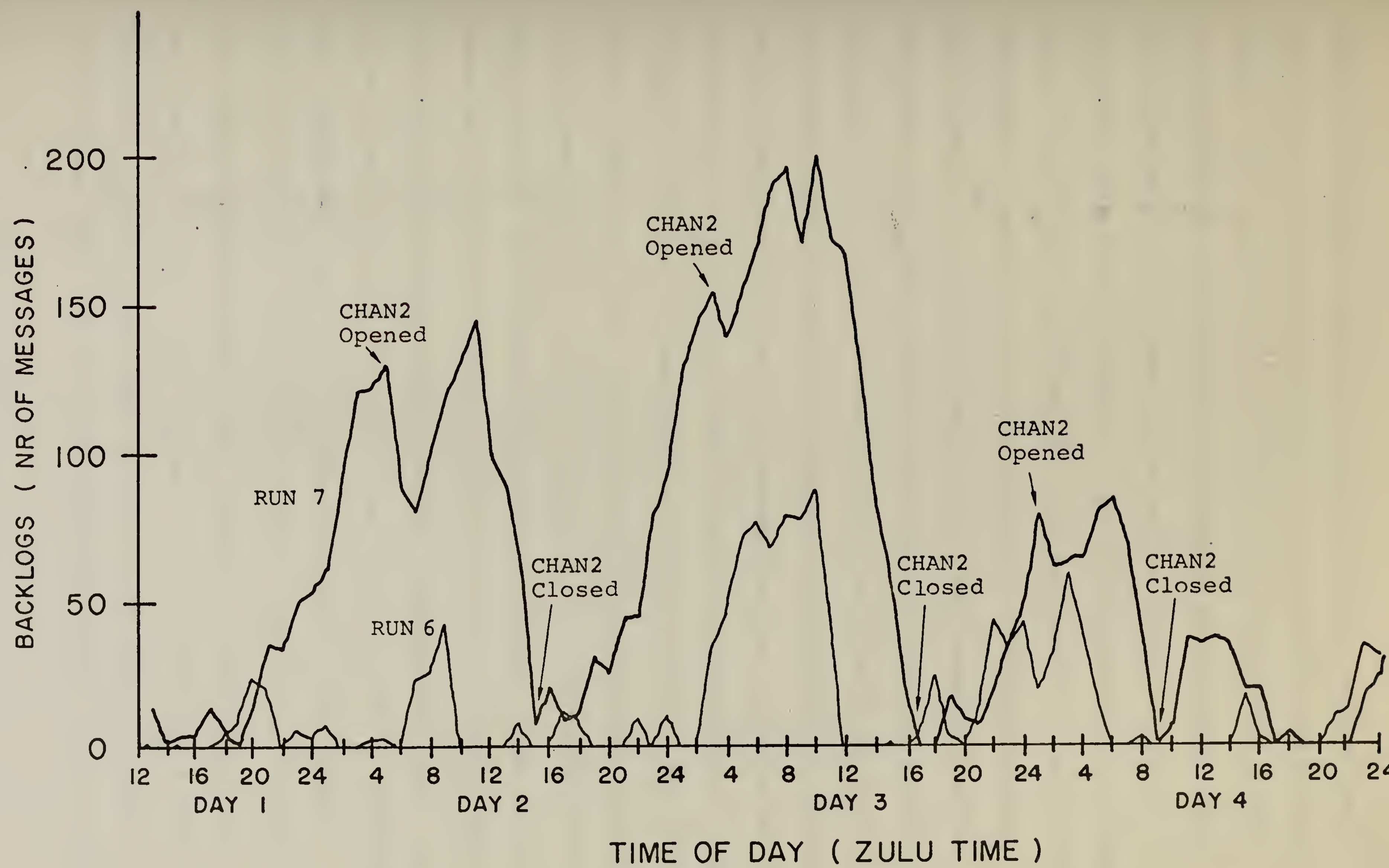


Figure 32. Total Backlogs for Simulation Runs 6 and 7 of High Traffic Loads (CHAN2 Open and CHAN2 Open/Closed).

channels transmit first run traffic and the rebroadcast facility is not used is superior to any other configuration. Recall that the decision variable for this problem is the average wait in queue of any precedence message such that this time does not exceed the Broadcast Speed of Service Criteria indicated in Table I. We also note that the primary goal of the fleet broadcast is to make timely and efficient delivery of traffic to all subscribers. The model shows that there is no question as to the timeliness of traffic delivery when both channels are running first run traffic. So now we must question whether this configuration is also the most efficient method. This can be answered by looking at the feedback loop and the message reruns. Looking at the results for the high load runs 5 and 6 where channel 2 was closed for first run messages in one run and open for first run in the other run. For these two runs the mean time delay in transmission of a screen request was 120 minutes and the mean service desk system delay was 158 minutes thus on the average it took 278 minutes (4.6 hours) for a screen request to reach the broadcast position for transmission since the time it was originated. Now if we chose the routine messages for comparison, we note that when channel 2 was closed to first run traffic the average time it took for a routine to be rerun is 2433 minutes (40.6 hours) as compared to 326 minutes (5.4 hours) when channel 2 was transmitting first run traffic. We also note that 15.5% of the total first run traffic was rerun in run 6 as compared to only 4.4% in run 5.

To fully explore this area we further look at the comparison of the runs where reruns were allowed to go to the head of the line. We see that although the reruns did not have to wait as long in queue as they did when they went to the back of the line, we also see that the first run traffic had a longer wait in queue on the average than when reruns were put at the back of the line. This leads us to ask the question, "Which type of message is most important?" It would appear that the first run message is most important because it has not been transmitted to any of the subscribers copying the broadcast and hence it is really undisclosed information while a rerun message has most likely been received by the majority of addressees, if more than one, and hence it is old information to those subscribers except for the subscriber who missed the message.

V. CONCLUSIONS

The conclusions which can be made are that the broadcast channel pair configuration where both channels transmit first run traffic is the superior configuration for timely delivery of traffic. The comparison of time delays for a subscriber to receive a rerun show that this configuration is not only timely, it is efficient as well. Therefore, the answer to the problem question is that the system should always be run with the parallel channels transmitting first run traffic and that the rebroadcast of first run traffic on the secondary channel should be discontinued.

APPENDIX A

ORIGIN OF THE STUDY

The problem on which this study is based was proposed as a thesis topic to this student in April 1971 by Captain F. M. Snyder, USN, then the Assistant Commander for Operations and Readiness to the Commander, Naval Communications Command (COMNAVCOMM). The study was officially commissioned as a thesis study by COMNAVCOMM message R 021944Z SEP 71. A copy of this message is shown below for reference and as an example of a Naval Communications teletype message.

```
CZCGAAØ5Ø
RTTUZYUW RHELSAAØØ65 2452ØØ4-UUU--RUWJAGA
ZNR UUUUU
R Ø21944Z SEP 71
FM COMNAVCOMM
TO RUWJAGA/NAVAL POSTGRADUATE SCHOOL
INFO RUWNSAA/NAVCOMMSTA SFRAN
BT
UNCLAS //NØØØØØ//
FOR LCDR. HARLAN D. OELMANN
THESIS STUDY
1. YOUR THESIS STUDY OUTLINE HAS BEEN REVIEWED AND ITS
PURSUIT IS STRONGLY ENCOURAGED. COMNAVCOMM REQUESTS
COPIES OF THE COMPLETED STUDY AND ANY INTERIM REPORTS
THAT ARE DEVELOPED.
2. DR. HARDY (OEG) WILL VISIT NAVCOMMSTA SANFRAN DURING
EARLY SEPT., AND IT IS SUGGESTED THAT YOU MEET OR SPEAK
WITH HIM AT THAT TIME IN ORDER TO BECOME APPRISED OF
OEG EFFORTS IN THIS FIELD.
3. SHOULD COMNAVCOMM ASSISTANCE APPEAR NECESSARY OR
DESIRABLE IN THE DEVELOPMENT OF THE STUDY, REQUEST YOU
MAKE YOUR NEEDS KNOWN VIA NAVCOMMSTA SANFRAN.
BT
```

APPENDIX B

PROBLEM BACKGROUND

I. A BRIEF EXPLANATION OF THE NAVAL COMMUNICATIONS SYSTEM

A. ORGANIZATION OF THE NAVAL COMMUNICATIONS SYSTEM

The Naval Communications System is composed of 27 Naval Communications Stations (NAVCOMMSTAs), 4 Naval Communications Units (NAVCOMMUs) and several Naval Radio Stations (NAVRADSTAs) [8]. These stations are located throughout the world and are organized into several Naval Communications Areas (NAVCOMMAREAs). The primary purpose of these stations is to relay messages to and from ships of the fleet and shore establishments within their area of responsibility. The stations within a NAVCOMMAREA are organized under one NAVCOMMSTA which is designated as the Naval Communications Area Master Station (NAVCAMS) while the other stations are designated as Naval Communications Area Local Stations (NAVCALS). Although the communication means which each of these stations use take several forms, such as teletype, voice and CW, etc., this study is concerned only with teletype communications and the fleet broadcast system. Therefore discussion will consider only those areas.

B. TELETYPE COMMUNICATIONS

It is assumed that to most readers, teletype communications is a familiar means of communication which does not

require detailed explanation, except to note that when messages are handled physically within a station they are handled in teletype tape or chad tape form. Hence in further discussion when we speak of messages being handled in a station it is implicitly meant that such messages are in tape form unless otherwise stated.

1. <u>World Wide Teletype Communications</u>

The Defense Department World Wide telecommunications system controlled by the Defense Communication Agency provides for long-haul and point-to-point telecommunications between communications stations of the Armed Forces which include the NAVCOMMSTAs and other stations within the NAVCOMMAREAs. This system is known as the AUTODIN network which is a digital high speed message transmission system.

2. <u>Local Teletype Communications</u>

The primary means of communications between a NAVCOMMSTA and the ships at sea is a teletype system which operates at the rate of 100 words-per-minute (wpm), where one teletype word is equivalent to 5 teletype characters.

There are essentially three methods of teletype communication between the ships at sea and the shore based NAVCOMMSTA.

The first is a ship-shore telecommunication link which are time shared circuits used by several ships at sea, these circuits provide the capability to send messages to a NAVCOMMSTA for further relay and delivery.

The second method is also a ship-shore link which is a dedicated circuit, sometimes called a full period termination circuit, between one ship and the NAVCOMMSTA. This type of circuit is normally used by the larger ships such as aircraft carriers and cruisers, which normally have staffs embarked. The full period termination circuit provides the capability for these ships to send messages to the NAVCOMMSTA for further relay and also to receive from the NAVCOMMSTA messages which are addressed to that particular ship or embarked staff.

The third method is the fleet broadcast system. This system is the primary means of delivering traffic to the fleet as a whole because it provides for simultaneous delivery of messages to the operating forces dispersed over a large geographical area. This method also employs a 100 wpm teletype system which could be described as a one way system because the broadcast system enables the NAVCOMMSTA only to send messages while the ships can only receive messages.

The fleet broadcast system is composed of several different types of broadcasts. These are the fleet multi-channel broadcast, on which this study is based, a single channel broadcast for ships that are not equipped to copy the multi-channel broadcast, the submarine broadcast and a merchant ship broadcast. In some NAVCOMMAREAs these broadcasts are all operated by one NAVCOMMSTA or Broadcast Control Station (BCS) while in other NAVCOMMAREAs these separate

broadcasts are operated by two or more NAVCOMMSTAs. Also if the capability of flexibility exists, a separate additional broadcast may be created within a NAVCOMMAREA to handle special traffic load situation. Sometimes a NAVCAMS may shift a braodcast to a NAVCALS in an emergency or to maintain proficiency among the capable NAVCALS in operating the broadcast.

C. MESSAGE PRECEDENCES AND SPEED OF HANDLING

Naval communicaions messages are assigned one of four precedences. Each message precedence has a Speed of Service Criteria assigned by reference 9, which is a time standard for a message to take in transmission from the origination of the message to the receipt of the message by the addressee.

These criteria are shown in Table XVI below. The letter in parenthesis is the designator of the precedence.

TABLE XVI

SPEED OF SERVICE CRITERIA

Precedence	Average Speed of Seriice	Limits
Flash (Z)	As fast as humanly possible	Same
Immediate (O)	30 minutes	30 minutes-1 hour
Priority (P)	3 hours	1-6 hours
Routine (R)	6 hours	3 hours-to the start of the next business day

II. THE FLEET MULTI-CHANNEL BROADCAST SYSTEM

There are normally five fleet multi-channel broadcasts operated in the Naval Communications System. Each broadcast which serves a particular ocean area is operated by a designated NAVCOMMSTA or Broadcast Control Station. These broadcasts have designations of NMUL, EMUL, KMUL, FMUL and GMUL, where FMUL serves the Eastern and Mid-Pacific Ocean area and is normally operated by NAVCOMMSTA San Francisco [10].

A. CHANNEL ALIGNMENT AND USE

The fleet multi-channel broadcast is a multiplex system which has 8 separate 100 wpm teletype traffic channels which are transmitted on a single carrier frequency. The alignment of the traffic channels is such that the overall broadcast traffic load to the fleet is segregated on the basis of ship type where each subscriber is served by two traffic channels, a primary channel and a secondary channel. An example of the overall broadcast channel alignment, channel designations and uses of each channel is shown in Table XVII below.

Only channel pairs 1 and 2, 3 and 4, and 5 and 7 will be considered for this study.

B. THE RECEPTION SIDE OF THE BROADCAST

The fleet multi-channel broadcast system for each channel is a guard system. This means that each subscriber copying a particular channel screens each sequentially serial-numbered

TABLE XVII

FMUL-BROADCAST CHANNEL ALIGNMENT

Channel	Designation	Use
1	FASW	Destroyer force primary traffic channel
2	FSPC	1 hour delayed rebroadcast of channel 1 or overload as necessary
3	FALD	Service, Amphibious and Mine force primary traffic channel
4	FUSN	1 hour delayed rebroadcast of channel 3 or overload as necessary
5	FNSC	Major warships (carriers, cruisers, large destroyers, including flagships) primary traffic channel
6	FOPI	Special traffic channel (Not of study interest)
7	FHIC	1 hour delayed rebroadcast of channel 5 or overload as necessary
8	FMET	Weather traffic channel (Not of study interest)

message sent on that channel to determine whether that particular message is addressed to him or not. If the message is for the ship or for the embarked staff the message is processed. If it is not for that particular ship or embarked staff the message is ignored and filed. Hence a subscriber must perform two necessary actions. He must determine from the message heading (which contains the addressees) whether the ship or embarked staff is an addressee or not. If the

message is addressed to the ship then it must be copied without errors from beginning to end. That is the addressee must have a clear enough copy that he is able to obtain all the information transmitted without any doubt as to what the message says.

If a subscriber has missed part or all of the heading such that he cannot determine whether the message was addressed to him or not, or if he has missed part or all of the text then we will refer to such a message as a "missed message."

A message may be missed for various reasons, some of which are: environmental or atmospheric conditions, which cause deterioration of the radio signal, equipment failure on the ship or in some cases error in judgment of the operator monitoring the teletype printer.

C. PROCEDURE FOR OBTAINING MISSED MESSAGES

If a subscriber copying a particular channel has missed one or more messages he must determine whether the message(s) was addressed to him and if necessary he must obtain a complete copy of the message. He is first encouraged to obtain a copy from another ship copying the same broadcast channel, providing the subscriber has a separate means of communication with the other ship. When the subscriber exhausts all local means of obtaining this information his next action is to originate a message which is called a "service or screen request message." Such a message is usually sent to a NAVCOMMSTA requesting them to verify or

screen their copy of the broadcast to determine whether the message(s) in question is for the subscriber. The NAVCOMMSTA will in turn reply by indicating which messages are of no concern to the subscriber and by rerunning on the primary channel those messages which were addressed to the subscriber. A subscriber which misses only a portion of a message may service only for that portion of the message to which the NAVCOMMSTA must in turn originate a service message in reply giving the subscriber that portion of the message missed.

It is noted that in some NAVCOMMAREAs, the NAVCOMMSTA to which a screen request is sent may not be the Broadcast Control Station. In these cases designated NAVCOMMSTAs in the NAVCOMMAREA also copy the broadcast and serve as stations which handle screen requests for a particular channel of the broadcast. When these NAVCOMMSTAs process a screen request their replys are relayed via AUTODIN to the Broadcast Control Station which in turn sends the reply on the appropriate broadcast channel. We note that these replys are handled in the same manner as first run messages.

D. HANDLING OF SERVICE MESSAGES AT A NAVCOMMSTA

Some NAVCOMMSTAs will handle screen requests for more than one broadcast channel or in some cases for more than one type of broadcast system. At each NAVCOMMSTA all such broadcast screen requests are usually handled at one broadcast service desk. The broadcast service desk handles these

requests on the highest precedence first and on a first in first out basis within precedences.

These service messages are usually referred to as screen requests, since the service desk clerk is required to "screen" the heading of the missed messages in the printed copy form of the broadcast channel log to determine if the message is for the requesting subscriber. Additionally, to clarify terminology, each message looked up is referred to as a "screen." Thus a "screen request" may contain one or more "screens."

After the service desk clerk determines the result of a screen request he then must make teletype tape copies of the messages to be rerun, if necessary, which are forwarded to the appropriate broadcast channel position for transmission. At some NAVCOMMSTAs, when the service desk clerk has finished the screen and before he prepares the rerun tapes he prepares a short message to the requester indicating which messages are of no concern to the subscriber and additionally states that those messages which are of concern will be rerun later. Other NAVCOMMSTAs use the procedure where they include this information with the first message rerun and only after the entire screen request has been processed.

It is apparent that this process is a very time consuming task and explains the reason why subscribers are encouraged to seek other sources for verification before asking the NAVCOMMSTA.

E. TRANSMISSION SIDE OF THE BROADCAST

Considering now the transmitting side of the broadcast we look at the NAVCOMMSTAs internal handling of messages which are destined for transmission on one or more of the broadcast channels. Messages arrive at the broadcast area in teletype tape form and are, depending on individual NAVCOMMSTA configurations, primarily delivered to each broadcast channel position by two 850 wpm reperforators called "burpees." The traffic delivered by the burpees is traffic which has been received by the NAVCOMMSTA from the AUTODIN network or from 100 wpm teletype circuits which terminate at the NAVCOMMSTA from any number of sources. The burpees are fed from these various sources through a small computer system called the Multiple Address Processing Unit (MAPU). This system reads the header of a message which contains address codes as to where a message is destined within the NAVCOMMSTA and routes that message to the appropriate relay positions by delivering a teletype tape through the burpees. In addition to the burpee deliveries some NAVCOMMSTAs hand deliver screen request answers, reruns and other messages to the broadcast position. The screen request answers and reruns are then usually put at the head of the line or queue for transmission.

Messages delivered to the broadcast position are put in a grid (queue) by precedence and in order of arrival within each precedence. The messages are then taken from the grid and put in the channel transmitter distributor (TD), a

device which reads the teletype tape for transmission. The order in which the messages are taken from the grid for transmission is on the highest precedence waiting and first in first out (FIFO) within a precedence basis. This process at some NAVCOMMSTAs is done by one man physically performing the queueing process while another man pulls the tapes from the grid and places them into the TDs for transmission. At other NAVCOMMSTAs, properly equipped, this entire process is handled by a small computer system, known as the "tight tape" system. In either case the queueing and transmission flow is the same for the purpose of this study.

APPENDIX C

GOODNESS OF FIT DATA ANALYSIS COMPUTER PROGRAM

I. DESCRIPTION OF CAPABILITY

The Goodness of Fit Data Analysis Program accepts any number of data samples of varying sizes and performs prescribed calculations and produces various graphs and tables which are used to analyze the fitting of an empirical distribution with a selected theoretical distribution. The program is written to fit the empirical data to two different distributions. These two distributions are the Exponential and the Hyperexponential probability distributions in either their regular form or the right shifted form.

The main program uses five different subroutines which are named SORT, STAT, HISTO, PLOTP and UTPLOT, the last two subroutines being used in conjunction with each other. The main program with the subroutines first sorts the data in ascending order and prints out the data in this form. Then the program calculates statistical parameters and prints out the parameter values which are later used in subsequent calculations. The next feature provides for sorting the data into frequency classes and prints a histogram of the data according to the number and widths of intervals as prescribed by the programmer. The program then calculates and plots the log of the tail distribution for both the

empirical and theoretical distributions being tested. A description of these calculations along with other mathematical descriptions are more fully explained below. The respective Cumulative Distribution Function (CDF) values are calculated and the absolute difference of the distribution points is determined and printed. The absolute difference provides the user this information for use in performing the Kolmogorov-Smirnov (K-S) Goodness of Fit Test on the data. The cumulative distribution functions are plotted to facilitate a graphical interpretation of the fit of the distributions. Finally the data is analyzed by performing the calculation of the Chi-Square Statistic and printing out a table of results for use in performing the Chi-Square Goodness of Fit Test.

Features of the program provide a flexibility of selecting only certain calculations to be performed and/or certain outputs to be printed. These features of selection are fully documented in the computer program shown in this Appendix.

This Appendix is not meant to be a user's guide for the program but rather to explain and reference the mathematical calculations used in the analysis program.

II. THE THEORETICAL DISTRIBUTIONS

A. THE EXPONENTIAL DISTRIBUTION

The exponential density function, cumulative distribution function and the associated parameters are given below.

$$f(x) = \lambda e^{-\lambda(x-a)} \qquad , x \geq a, \text{ where a is the right shift parameter.}$$

$$= 0 \qquad , x < a,$$

$$F(x) = 1-e^{-\lambda(x-a)} \qquad , x \geq a,$$

$$= 0 \qquad , x < a.$$

$$\mu = E(X) = \frac{1}{\lambda} + a,$$

$$\lambda = \frac{1}{\mu - a},$$

$$\sigma^2 = VAR(X) = \frac{1}{\lambda^2}.$$

B. THE HYPEREXPONENTIAL DISTRIBUTION

The hyperexponential distribution shown below is a mixture of two exponential distributions. The observations originate in two populations only, with probabilities p and 1-p and parameters $2\lambda p$ and $2\lambda(1-p)$, respectively [11].

The hyperexponential density function, cumulative distribution function and the associated parameters are given below.

$$f(x) = 2p^2\lambda e^{-2p\lambda(x-a)} + 2(1-p)\lambda e^{-2(1-p)\lambda(x-a)}, \quad x \geq a,$$

$$= 0 \quad , \quad x < a,$$

$$F(x) = p\left[1-e^{-2p\lambda(x-a)}\right] + (1-p)\left[1-e^{-2(1-p)\lambda(x-a)}\right], \quad x \geq a,$$

$$= 0 \quad , \quad x < a,$$

where a is the right shift parameter.

$$\mu = E(X) = \frac{1}{\lambda} + a,$$

$$\lambda = \frac{1}{\mu - a},$$

$$\sigma^2 = \mathrm{VAR}(X) = \frac{1}{\lambda^2}\left[\frac{1}{2p(1-p)} - 1\right],$$

$$p = \frac{1}{2} - \frac{1}{2}\left[1 - \frac{2}{\frac{\sigma^2}{\mu} + 1}\right]^{\frac{1}{2}}.$$

III. STATISTICAL AND GRAPH CALCULATIONS

A. SAMPLE STATISTICAL PARAMETERS

The analysis program has a feature in which preselected values for the mean, the right shift parameter a and the hyperexponential parameter p can be read in instead of having the program calculate these estimates from the data. When this feature is not used some of these parameters are calculated by the subroutine STAT using the familiar formulas shown below.

$$\mathrm{XBAR} = \bar{X} = \frac{\sum\limits_{i=1}^{N} X_i}{N}, \qquad \mathrm{VAREST} = \frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X})^2.$$

We note that

$$\mathrm{XBAR} = \mu = \frac{1}{\lambda} + a = \frac{1}{\mathrm{LAMEST}} + A,$$

hence,

$$\mathrm{LAMEST} = \frac{1}{(\mathrm{XBAR} - A)}.$$

The capitalized names are those used in the program for these various parameters.

The estimate of the hyperexponential parameter p is calculated using the same formula shown above except that XBAR = μ and VAREST = σ^2.

The right shift parameter a can also be specified to be the minimum order statistic of the data sample.

B. A GRAPHICAL PROCEDURE OF TESTING FOR EXPONENTIALITY

When comparing empirical data to the exponential distribution, for goodness of fit, this graphical technique provides an appealing method of either supporting or denying the more purely statistical comparisons to be described below.

If the empirical data is really distributed exponentially with a cumulative distribution function as shown above then the following graphical comparison can be made [12]. For the exponential distribution the log of the reciprocal of the tail distribution (called the log of the tail for brevity) is:

$$y = \log \frac{1}{1-F(x)} = \frac{(x-a)}{\mu}, \quad \text{assuming } \mu > 0.$$

Thus if we plot y against x, we get a straight line with a slope of $\frac{1}{\mu}$ and the line will cut the x-axis at the point x=a.

If we have n data points in the empirical data, we can sort the n points in ascending order forming the order statistics, i.e., $x_1 \leq x_2 \leq \ldots\ldots\ldots\ldots \leq x_n$. The empirical cumulative distribution function is defined as

$$F(x_i) = \frac{i}{n} \, .$$

If we let $y = \log \frac{1}{1-F(x_i)}$. Then by plotting y_i against x_i the plotted points can be compared to the fitted straight line as a test of the exponential assumption.

It is noted that the program has the option of using a preselected mean or using the sample mean estimate in calculating the straight line. Thus, this graphical comparison can be used to make an independent estimate of the mean by determining the slope of the empirical data. Then the data can be rerun with a preselected mean to attempt a better fit.

When the log of the tail distribution is used with the hyperexponential comparison we get a decreasing failure rate function for the hyperexponential distribution. That is we get a concave curve. In this case the graphical comparison can also be used to determine how close the two compare.

This method of distribution fitting can be used when empirical data is analyzed for the first time. Through the use of the log of the tail graph we can determine how the distribution behaves and find out whether it has a decreasing or increasing failure rate and thus plan further analysis on the data.

C. THE KOLMOGOROV-SMIRNOV GOODNESS OF FIT TEST

The Kolmogorov-Smirnov Goodness of Fit Test is a familiar test and therefore will not be described here [13].

It is noted that the program only calculates the absolute difference between the F(x) values of the two distributions and prints the results. Therefore the user must scan the

points to find the maximum difference and then enter the appropriate Kolmogorov-Smirnov table to determine the results of this test.

The Kolmogorov-Smirnov test is regarded by most references as a more powerful test than the Chi-Square Goodness of Fit Test but it has one drawback, that being that the Kolmogorov-Smirnov statistic becomes inflated when the data has large groups of points which are of equal value.

D. THE CHI-SQUARE GOODNESS OF FIT TEST

The Chi-Square Goodness of Fit Test is also a familiar test and will be described only briefly [12,14,15].

It is well known that the chi-square goodness of fit test has several drawbacks. Among them are its large sample character and the dependence upon the careful choice of the number and the widths of the intervals. Therefore this test should be used with caution. For further discussion of these characteristics see reference 14.

It is also noted that the program has the capability of either reading in a specified mean or estimating it. This will affect the number of degrees of freedom used when testing the chi-square statistic against the appropriate table values. The chi-square goodness of fit test with an estimated mean uses (k-2) degrees of freedom or (k-1) degrees of freedom when the mean is preselected, where k is the number of intervals (or classes) used in the test, and where the x-axis is divided into the intervals $x_1 \leq x_2 \leq \ldots\ldots \leq x_{k-1}$.

The chi-square statistic was calculated in the following manner. Let o_i be the observed number of data points in the i^{th} interval and let e_i be the expected number of data points in the i^{th} interval, where $e_i = np_i$ and where n is the number of data points in the sample being tested and p_i is calculated as indicated below for the appropriate distribution.

For the exponential distribution:

$$p_i = \int_{x_i}^{x_i+1} \lambda e^{-\lambda(t-a)} dt = e^{-\lambda(x_i-a)} - e^{-\lambda(x_{i+1}-a)}, \qquad i=1,\ldots,k-2,$$

and

$$p_i = \int_{x_{k-1}}^{\infty} \lambda e^{-\lambda(t-a)} dt = e^{-\lambda(x_{k-1}-a)}, \quad i = k-1.$$

For the hyperexponential distribution:

$$p_i = \int_{x_i}^{x_{i+1}} \left[2p^2\lambda e^{-2p\lambda(t-a)} + 2(1-p)\lambda e^{-2(1-p)\lambda(t-a)}\right] dt$$

$$= p\left[e^{-2p\lambda(x_i-a)} - e^{-2p\lambda(x_{i+1}-a)}\right] + (1-p)\left[e^{-2(1-p)\lambda(x_i-a)} - e^{-2(1-p)\lambda(x_{i+1}-a)}\right], \qquad i=1,\ldots,k-2,$$

and

$$p_i = \int_{x_{k-1}}^{\infty} \left[2p^2\lambda e^{-2p\lambda(t-a)} + 2(1-p)\lambda e^{-2(1-p)\lambda(t-a)}\right] dt$$

$$= pe^{-2p\lambda(x_{k-1}-a)} + (1-p)^{-2(1-p)\lambda(x_{k-1}-a)}, \quad i=k-1.$$

The value e_i was restricted to the condition of having $e_i \geq 5$ for each interval [14]. If this condition is not satisfied then the observations of that interval are added to the previous interval and the appropriate integral is recalculated. This is repeated until this condition is satisfied.

Finally the chi-square statistic is determined by this formula

$$\chi^2_{stat} = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i} .$$

This statistic is then compared to the appropriate chi-square table value to determine the results of the test.

IV. DATA ANALYSIS COMPUTER PROGRAM

```
C
C                      GOODNESS OF FIT
C                   DATA ANALYSIS PROGRAM
C
C
C   PROGRAM DISCRIPTION:
C
C   SORTS DATA IN ASCENDING ORDER AND PRINTS DATA
C   CALCULATES PARAMETERS: MEAN, VAR, STD.DEV., LAMEST
C   AND HYPEREXPONENTIAL PROPORTION PARAMETERS P1 AND P2
C
C   HISTOGRAMS SORTED DATA
C
C   CALCULATES AND PLOTS THE NATURAL LOG OF THE RECIPROCAL
C   OF THE TAIL DISTRIBUTION FOR BOTH THE EMPIRICAL AND
C   THE THEORETICAL DISTRIBUTIONS
C
C   CALCULATES THE C.D.F.'S FOR BOTH THE EMPIRICAL AND
C   THE THEORETICAL DISTRIBUTIONS AND DETERMINES THE
C   ABSOLUTE DIFFERENCE BETWEEN THE TWO C.D.F.'S FOR USE
C   IN THE KOLMOGOROV-SMIRNOV  GOODNES OF FIT TEST
C
C   PLOTS THE C.D.F.'S OF THE EMPIRICAL AND THEORETICAL
C   DISTRIBUTIONS ON THE SAME GRAPH
C
C   CALCULATES CHI-SQUARE STATISTIC
C   PRINTS A TABLE OF THE CHI-SQUARE CALCULATION RESULTS
C
      REAL X(450),Y(450,4),Z(450)
      REAL YY(450),XR(450)
      REAL FREQ(100),RANGE(100)
      REAL FREQ1(20),RANGE1(20),TITLE(20)
      REAL P(100),E(100),XX(100,3)
      REAL INC,LAMEST
      INTEGER TYDIST,RS
      INTEGER DPS,PPS,HPS,LPS,KPS,CPS,CSPS
C
C   DEFINE:  NUMTIM--NR OF SETS OF DATA TO BE ANALYZED
C
C
C   DEFINE:  TYPE OF THEORETICAL DISTRIBUTION TO BE USED
C            TO FIT DATA
C
C          TYDIST--FOR EXPONENTIAL DIST SET TYDIST=0
C                  FOR HYPEREXPONENTIAL DIST SET TYDIST=1
C
C   DEFINE:  RIGHT SHIFT OPTION
C
C          RS--REGULAR OR RIGHT SHIFTED DIST WITH DEFINED
C              VALUE FOR AA, I.E., REGULAR DIST AA=0.0
C              SET RS=0 OR READ SPECIFIED VALUE FOR AA BELOW
C              RIGHT SHIFT SET RS=1 THEN AA=MIN ORDER STAT
C
      READ(5,1001)NUMTIM,TYDIST,RS
 1001 FORMAT(3I5)
C
C   DEFINE:  IN1---NR OF INTERVALS USED IN (FIRST) HISTOGRAM
C                  AND FOR INITIAL CHI-SQUARE CALCULATION
C                  (MAX=20)
C            IN----IN IS THE TOTAL NR OF INTERVALS (MAX=40)
C                  TO BE USED
C                  IF IN GT 20 THIS PROVIDES TWO HISTOGRAMS
C                  IF ONLY ONE HISTOGRAM DESIRED SET IN=IN1
```

```
C            INCD--INCREMENT DETERMINATOR.  USED TO CONTROL
C                  THE WIDTH OF EACH HISTOGRAM AND CHI-SQUARE
C                  INTERVAL, I.E., INC=(B-A)/INCD
C            A,B---LOW AND HIGH RANGES OF HISTOGRAM(S)
C            INCS--IF GT 40 INTERVALS ARE DESIRED FOR
C                  CHI-SQUARE CALCULATION INDICATE NUMBER
C                  DESIRED (MAX=100).
C                  IF INCS NOT DEFINED SET INCS=0
C            INCSD-INCREMENT DETERMINATOR FOR CHI-SQUARE
C                  INTERVAL WIDTH. NOTE: MUST BE DEFINED WHEN
C                  INCS,C,AND D ARE DEFINED.
C            C,D---LOW AND HIGH RANGES FOR CHI-SQUARE
C                  INTERVALS GT 40
C                  IF INCS NE 0 THEN C AND D MUST BE DEFINED
C
C  READ STATEMENTS 1101 AND 1201 CAN BE MOVED INSIDE OF
C  9999 DO LOOP TO ALLOW CONTROL CHANGES ON INDIVIDUAL DATA
C  DECKS
C
      READ(5,1101)IN1,IN,INCD,A,B,INCS,INCSD,C,D
 1101 FORMAT(3I5,2F10.2,2I5,2F10.2)
C
C  DEFINE: PRINT SUPPRESSION OPTION.  IF PRINTOUT OF
C          INDICATED INFORMATION IS DESIRED SET=0, IF NOT
C          DESIRED SET=1.
C
C          DPS--PRINT OF SORTED DATA
C          PPS--PRINT OF DATA PARAMETERS
C          HPS--PRINT OF HISTOGRAM(S)
C          LSP--PLOT OF LN OF TAIL DIST.
C          KPS--PRINT OF CDF VALUES AND KLOMOGOROV-SMIRNOV
C               STATISTIC
C          CPS--PLOT OF C.D.F.'S
C          CSPS-PRINT OF CHI-SQUARE STATISTIC
C
      READ(5,1201)DPS,PPS,HPS,LPS,KPS,CPS,CSPS
 1201 FORMAT(7I5)
C
C  START DO LOOP WHICH PROCESSES EACH SET OF DATA
C
      DO 9999 L=1,NUMTIM
C
C  READ IN TITLE OF DATA SET
C
      READ(5,2001)TITLE
 2001 FORMAT(20A4)
C
C  DEFINE: SAMPLE SIZE N
C
C  DEFINE: OPTION ALLOWS READING IN MEAN VALUE TO BE USED IN
C          CDF, LN TAIL DIST AND CHI-SQUARE CALCULATIONS
C          OPTION ALSO ALLOWS SPECIFYING VALUES FOR AA
C          OR FOR SPECIFYING VALUES FOR P1 AND P2 IN HYPER-
C          EXPONENETIAL DISTRIBUTION
C
C          RXBAR--READ IN MEAN VALUE
C          AA--OFFSET SPECIFIED FOR EITHER REGULAR (AA=0.0)
C              DIST OR RIGHT SHIFTED DIST AA=READ IN VALUE
C          P1,P2--SPECIFY HYPEREXP PARAMETERS  NOTE: P2=1-P1
C                 IF NOT USED SET =0
C
      READ(5,3001)N,RXBAR,AA,P1,P2
 3001 FORMAT(I5,F10.2,F5.2,2F5.4)
C
C  READ IN DATA SET
C
      READ(5,4001)(X(I),I=1,N)
 4001 FORMAT(16F5.0)
C
C  LOAD RANGE VECTOR
C
      INC=(B-A)/INCD
```

```
      RANGE(1)=A+INC
      DO 1000 I=2,IN
      RANGE(I)=RANGE(I-1)+INC
 1000 CONTINUE
C
C   LOAD A LARGE NUMBER IN RANGE(IN) SO WHEN PRINTED OUT IN
C   F5.0 FORMAT OR SIMILAR FORMAT IT WILL PRINT AS ***** TO
C   INDICATE INFINITY
C
      RANGE(IN)=10000.0
C
C   SORT DATA IN ASCENDING ORDER
C
      CALL SORT(X,N)
C
C   CALCULATE PARAMETERS
C
      CALL STAT(X,N,XBAR,VAR,S)
C
C   AA DEFINES THE OFFSET IS A RIGHT SHIFTED DIST IS USED
C
      IF(RS.EQ.0)GO TO 1310
      AA=X(1)
 1310 LAMEST=1.0/(XBAR-AA)
      RLAM=0.0
      IF(RXBAR.EQ.0.0)GO TO 1610
      RLAM=1.0/(RXBAR-AA)
 1610 IF(TYDIST.EQ.0)GO TO 1710
      IF(P1.NE.0)GO TO 1710
C
C   CALCULATE P1 AND P2 PARAMETERS FOR HYPEREXPONENTIAL DIST
C   IF REQUIRED
C
      P1=0.5-0.5*SQRT(1.0-2.0/(VAR/XBAR**2+1.0))
      P2=1.0-P1
 1710 IF(DPS.EQ.1)GO TO 1810
C
C   WRITE SORTED DATA AND PARAMETERS
C
      WRITE(6,1002)TITLE,(X(I),I=1,N)
 1002 FORMAT('1',T10,'DATA POINTS AND ESTIMATED PARAMETERS'
     X' FOR:',20A4//(10F11.2))
 1810 IF(PPS.EQ.1)GO TO 1910
      IF(DPS.EQ.1)WRITE(6,2002)TITLE
 2002 FORMAT('1',T10,'ESTIMATED PARAMETERS FOR:',20A4)
      WRITE(6,2102)XBAR,VAR,S,LAMEST,N,RXBAR,RLAM,P1,P2,AA
 2102 FORMAT(//T7,'XBAR=',F11.2,'   VAREST=',F15.2,
     X'   STD.DEV.=',F11.2,
     X'   LAMEST=',F11.7,'   SAMPLE SIZE=',I4/T7,'RXBAR=',
     XF11.2,'   RLAM=',F11.7,'   P1=',F6.4,'   P2=',F6.4,
     X'   AA=',F6.2)
 1910 IF(RXBAR.EQ.0.0)GO TO 2010
      XBAR=RXBAR
      LAMEST=RLAM
C
C   ZERO OUT FREQ VECTOR
C
 2010 DO 2000 I=1,IN
      FREQ(I)=0.0
 2000 CONTINUE
C
C   DETERMINE FREQ OF DATA IN INTERVALS FOR HISTOGRAM AND
C   CHI-SQUARE CALCULATION
C
      N1=IN-2
      DO 3000 J=1,N
      IF(X(J).LE.RANGE(1))FREQ(1)=FREQ(1)+1
      IF(X(J).GT.RANGE(IN-1))FREQ(IN)=FREQ(IN)+1
      DO 3100 I=1,N1
      IF(X(J).GT.RANGE(I).AND.X(J).LE.RANGE(I+1))
     XFREQ(I+1)=FREQ(I+1)+1
 3100 CONTINUE
```

```
 3000 CONTINUE
      IF(HPS.EQ.1)GO TO 3900
C
C   PRINT OUT FIRST HISTOGRAM
C
      CALL HISTO(IN1,FREQ,RANGE,TITLE)
C
C   DETERMINE IF MORE THAN ONE HISTOGRAM IS DESIRED
C
      IF(IN.EQ.IN1)GO TO 3900
      IN2=IN-IN1
      NSTART=IN1+1
      DO 3200 J=NSTART,IN
      RANGE1(J-IN1)=RANGE(J)
      FREQ1(J-IN1)=FREQ(J)
 3200 CONTINUE
      CALL HISTO(IN2,FREQ1,RANGE1,TITLE)
C
C   CALCULATE VALUES FOR PLOT OF NATURAL LOG OF THE
C   RECIPROCAL OF THE TAIL DISTRIBUTION
C
C   CALCULATE LN OF TAIL DIST FOR EMP DIST  PUT IN Y(I,1)
C   CALCULATE EXPONENTIAL F(X) AND PUT IN Y(I,2)
C   CALCULATE STRAIGHT LINE BENCHMARK FOR GRAPH PUT IN Y(I,3)
C   NOTE: CALCULATION OF THE STRAIGHT LINE IS NECESSARY ONLY
C   WHEN TESTING A THEOR. DISTRIBUTION OTHER THAN THE  EXP
C   CALCULATE LN OF TAIL DIST FOR THEOR DIST PUT IN Y(I,4)
C   CALCULATION MADE FOR N-1 DATA PTS TO AVOID TAKING LN(0)
C
 3900 NS=N-1
      ARG1=N
      IF(TYDIST.EQ.1)GO TO 4010
      DO 4000 I=1,NS
      ARG2=N-I
      ARG=ARG1/ARG2
      Y(I,1)=ALOG(ARG)
      Y(I,2)=1.0-EXP(-(LAMEST*(X(I)-AA)))
      Y(I,3)=(X(I)-AA)/XBAR
      Y(I,4)=ALOG(1.0/(1.0-Y(I,2)))
 4000 CONTINUE
C
C   INCLUDE LAST DATA POINT IN THEOR CDF FOR CDF PLOT BELOW
C
      Y(N,2)=1.0-EXP(-(LAMEST*(X(N)-AA)))
      GO TO 4110
 4010 DO 4050 I=1,NS
      ARG2=N-I
      ARG=ARG1/ARG2
      Y(I,1)=ALOG(ARG)
      Y(I,2)=P1*(1.0-EXP(-2.0*P1*LAMEST*(X(I)-AA)))+
     XP2*(1.0-EXP(-2.0*P2*LAMEST*(X(I)-AA)))
      Y(I,3)=(X(I)-AA)/XBAR
      Y(I,4)=ALOG(1.0/(1.0-Y(I,2)))
 4050 CONTINUE
C
C   INCLUDE LAST DATA POINT IN THEOR CDF FOR CDF PLOT BELOW
C
      Y(N,2)=P1*(1.0-EXP(-2.0*P1*LAMEST*(X(I)-AA)))+
     XP2*(1.0-EXP(-2.0*P2*LAMEST*(X(I)-AA)))
C
C   PLOT LN OF TAIL DIST
C
 4110 IF(LPS.EQ.1)GO TO 5110
      WRITE(6,1102)TITLE
 1102 FORMAT('1',T10,'PLOT OF LN(1.0/1.0-F(X)) FOR:  ',
     X20A4//)
      DO 4100 I=1,NS
      YY(I)=Y(I,3)
 4100 CONTINUE
      CALL PLOTP(X,YY,NS,1)
      DO 4200 I=1,NS
      YY(I)=Y(I,1)
```

```
 4200 CONTINUE
      CALL PLOTP(X,YY,NS,2)
      DO 4300 I=1,NS
      YY(I)=Y(I,4)
 4300 CONTINUE
      CALL PLOTP(X,YY,NS,3)
C
C  CALCULATION OF THE EMPIRICAL C.D.F. AND THE STATISTICS
C  FOR THE KOLMOGOROV-SMIRNOV TEST
C  WRITE C.D.F. VALUES AND THE K-S STATISTICS
C
      DEM=N
      DO 5000 I=1,N
      Y(I,1)=I/DEM
      Z(I)=ABS(Y(I,1)-Y(I,2))
 5000 CONTINUE
 5110 IF(KPS.EQ.1)GO TO 6110
      WRITE(6,3002)TITLE
 3002 FORMAT('1',T10,'C.D.F. VALUES AND KOLMOGOROV-SMIRNOV '
     X'STATISTIC FOR:'//T10,20A4//T13,'X',T20,'EMP DIST  '
     X'EST DIST   K-S STAT'/)
      DO 6000 I=1,N
      WRITE(6,4002)X(I),(Y(I,J),J=1,2),Z(I)
 4002 FORMAT(T9,F7.2,T20,F8.4,2F11.4)
 6000 CONTINUE
 6110 IF(CPS.EQ.1)GO TO 9110
C
C  GRAPH THE EMP AND THEORETICAL C.D.F.S
C
      WRITE(6,4202)TITLE
 4202 FORMAT('1',T10,'EMPIRICAL(.) AND THEORETICAL(+) CDF '
     X'FOR:',20A4//)
C  ADD 0.0 IN X AND YY VECTORS SUCH THAT THE CDF PLOT WILL
C  AUTOSCALE FROM 0.0
      N2=N+1
      XR(1)=0.0
      YY(1)=0.0
      DO 7000 I=2,N2
      XR(I)=X(I-1)
      YY(I)=Y(I-1,1)
 7000 CONTINUE
      CALL PLOTP(XR,YY,N2,1)
      DO 8000 I=2,N2
      YY(I)=Y(I-1,2)
 8000 CONTINUE
      CALL PLOTP(XR,YY,N2,3)
C
 9110 IF(CSPS.EQ.1)GO TO 9999
C
C  REDEFINE AND RELOAD RANGE AND FREQ VECTORS FOR CHI-SQUARE
C  CALCULATION.  IF INCS=0 THEN BYPASS ROUTINE
C
      IF(INCS.EQ.0)GO TO 0099
C
C  STORE VALUE OF IN FOR NEXT DECK OF DATA TO BE PROCESSED
C
      TEMPIN=IN
      IN=INCS
C
C  LOAD RANGE VECTOR
C
      INC=(D-C)/INCSD
      RANGE(1)=C+INC
      DO 9000 I=2,IN
      RANGE(I)=RANGE(I-1)+INC
 9000 CONTINUE
C
C  LOAD A LARGE NUMBER IN RANGE(IN) SO WHEN PRINTED OUT IN
C  F5.0 FORMAT OR SIMILAR FORMAT IT WILL PRINT AS ***** TO
C  INDICATE INFINITY
C
      RANGE(IN)=10000.0
```

```
C
C   ZERO OUT FREQ VECTOR
C
       DO 9100 I=1,IN
       FREQ(I)=0.0
 9100  CONTINUE
C
C   DETERMINE FREQ OF DATA IN INTERVALS FOR CHI-SQUARE
C   CALCULATION
C
       N1=IN-2
       DO 9200 J=1,N
       IF(X(J).LE.RANGE(1))FREQ(1)=FREQ(1)+1
       IF(X(J).GT.RANGE(IN-1))FREQ(IN)=FREQ(IN)+1
       DO 9300 I=1,N1
       IF(X(J).GT.RANGE(I).AND.X(J).LE.RANGE(I+1))
      XFREQ(I+1)=FREQ(I+1)+1
 9300  CONTINUE
 9200  CONTINUE
C
C   CALCULATE CHI-SQUARE STATISTIC
C
C   ZERO OUT XX(I,J),P(I),E(I)
C
 0099  DO 0100 I=1,IN
       P(I)=0.0
       E(I)=0.0
       DO 0110 J=1,3
       XX(I,J)=0.0
 0110  CONTINUE
 0100  CONTINUE
C
C   LOAD INTERVAL BOUNDARIES(RANGES) AND FREQS IN XX ARRAY
C   SUBJECT OT E(I).GT.5.0.
C   ALSO CALCULATE P(I) AND E(I).
C
C
C   CALCULATIONS FOR EXPONENTIAL DISTRIBUTION
C
       IF(TYDIST.EQ.1)GO TO 0111
       M=1
       XX(1,1)=AA
       DO 0200 I=1,IN
       TEMP=0.0
       DO 0300 J=M,IN
       TEMP=TEMP+FREQ(J)
       XX(I,2)=RANGE(J)
       IF(J.EQ.IN)GO TO 0320
       XX(I+1,1)=XX(I,2)
       P(I)=EXP(-(LAMEST*(XX(I,1)-AA)))-EXP(-(LAMEST*
      X(XX(I,2)-AA)))
       E(I)=N*P(I)
       IF(E(I).GE.5.0)GO TO 0310
 0300  CONTINUE
 0310  XX(I,3)=TEMP
       M=J+1
 0200  CONTINUE
C
C   FOR LAST INTERVAL TEST IF E(I).LT.5.0, IF SO STORE IN
C   PREVIOUS INTERVAL AND RECALCULATE E(I-1)
C
 0320  P(I)=EXP(-(LAMEST*(XX(I,1)-AA)))
       E(I)=N*P(I)
       IF(E(I).GE.5.0)GO TO 0330
       XX(I-1,3)=XX(I-1,3)+TEMP
       XX(I-1,2)=RANGE(IN)
       XX(I,1)=0.0
       XX(I,2)=0.0
       XX(I,3)=0.0
       P(I-1)=EXP(-(LAMEST*(XX(I-1,1)-AA)))
       E(I-1)=N*P(I-1)
       P(I)=0.0
```

```
      E(I)=0.0
      GO TO 0400
 0330 XX(I,3)=TEMP
      GO TO 0400
C
C  CALCULATIONS FOR HYPEREXPONENTIAL DISTRIBUTION
C
 0111 M=1
      XX(1,1)=AA
      DO 0201  I=1,IN
      TEMP=0.0
      DO 0301  J=M,IN
      TEMP=TEMP+FREQ(J)
      XX(I,2)=RANGE(J)
      IF(J.EQ.IN)GO TO 0321
      XX(I+1,1)=XX(I,2)
      P(I)=P1*(EXP(-2.0*P1*LAMEST*(XX(I,1)-AA))-EXP(-2.0*P1*
     XLAMEST*(XX(I,2)-AA)))+P2*(EXP(-2.0*P2*LAMEST*
     X(XX(I,1)-AA))-EXP(-2.0*P2*LAMEST*(XX(I,2)-AA)))
      E(I)=N*P(I)
      IF(E(I).GE.5.0)GO TO 0311
 0301 CONTINUE
 0311 XX(I,3)=TEMP
      M=J+1
 0201 CONTINUE
C
C  FOR LAST INTERVAL TEST IF E(I).LT.5.0, IF SO STORE IN
C  PREVIOUS INTERVAL AND RECALCULATE E(I-1)
C
 0321 P(I)=P1*EXP(-2.0*P1*LAMEST*(XX(I,1)-AA))+P2*EXP(-2.0*
     XP2*LAMEST*(XX(I,1)-AA))
      E(I)=N*P(I)
      IF(E(I).GE.5.0)GO TO 0331
      XX(I-1,3)=XX(I-1,3)+TEMP
      XX(I-1,2)=RANGE(IN)
      XX(I,1)=0.0
      XX(I,2)=0.0
      XX(I,3)=0.0
      P(I-1)=P1*EXP(-2.0*P1*LAMEST*(XX(I-1,1)-AA))+P2*
     XEXP(-2.0*P2*LAMEST*(XX(I-1,1)-AA))
      E(I-1)=N*P(I-1)
      P(I)=0.0
      E(I)=0.0
      GO TO 0400
 0331 XX(I,3)=TEMP
C
C  CALCULATE TOTALS OF P(I), E(I) AND XX(I,3)
C
 0400 XSUM=0.0
      PSUM=0.0
      ESUM=0.0
      DO 0500  I=1,IN
      XSUM=XSUM+XX(I,3)
      PSUM=PSUM+P(I)
      ESUM=ESUM+E(I)
 0500 CONTINUE
C
C  TEST TO FIND THE NUMBER OF INTERVALS IN XX(I,J) THAT ARE
C  IN ORDER TO DETERMINE THE NUMBER OF DEGRESS OF FREEDOM
C
      DO 0600  I=1,IN
      IF(XX(I,2).EQ.0.0)GO TO 0610
 0600 CONTINUE
 0610 NINT=I-1
      NDF=NINT-2
C
C  CALCULATE THE CHI-SQUARE STATISTIC
C
      CHISUM=0.0
      DO 0700  I=1,NINT
      CHISUM=CHISUM+((XX(I,3)-E(I))**2)/E(I)
 0700 CONTINUE
```

```
C
C  WRITE THE CHI-SQUARE TEST RESULTS
C
      WRITE(6,0502)TITLE
 0502 FORMAT('1',T10,'CHI-SQUARE TEST RESULTS FOR:',20A4//
     XT10,'INTERVALS',T27,'FREQ',T45,'INTERVAL',T65,'EST OF'
     X/T8,'LOW',T17,'HIGH',T27,'COUNT',T47,'PROB',T60,
     X'NO. IN INTERVAL')
      DO 0800 I=1,NINT
      WRITE(6,0602)XX(I,1),XX(I,2),XX(I,3),P(I),E(I)
 0602 FORMAT(F10.2,4X,F6.2,F10.0,F21.4,F20.2)
 0800 CONTINUE
      WRITE(6,0702)XSUM,PSUM,ESUM,NINT,NDF,CHISUM,XBAR,
     XLAMEST
 0702 FORMAT(T6,'TOTALS',T21,F10.0,F21.4,F20.2//T10,
     X'NO. OF INTERVALS=',I4//T10,'DEGREES OF FREEDOM=',I4//
     XT10,'CHI-SQUARE STATISTIC=',F10.2//T10,'EST OF MEAN=',
     XF10.2//T10,'LAMEST=',F10.4)
      IF(INCS.EQ.0)GO TO 9999
      IN=TEMPIN
 9999 CONTINUE
      STOP
      END


      SUBROUTINE SORT(A,N)
      DIMENSION A(N)
      NPASS=N-1
      DO 1000 I=1,NPASS
      NSTOP=N-I
      DO 1000 J=1,NSTOP
      IF(A(J).LE.A(J+1))GO TO 1000
      TEMP=A(J)
      A(J)=A(J+1)
      A(J+1)=TEMP
 1000 CONTINUE
      RETURN
      END


      SUBROUTINE STAT(X,N,XBAR,VAR,S)
      REAL X(N)
      SUM=0.0
      DO 1 I=1,N
1     SUM=SUM+X(I)
      XBAR=SUM/N
      VAR=0.0
      DO 2 I=1,N
2     VAR=VAR+(X(I)-XBAR)**2
      VAR=VAR/(N-1)
      S=SQRT(VAR)
      RETURN
      END


      SUBROUTINE HISTO(IN,FREQ,RANGE,TITLE)
      DIMENSION FREQ(20),RANGE(20),JOUT(20),TITLE(20)
      DATA NOTH/'    '/,K/'****'/
      WRITE (6,4) TITLE
    4 FORMAT('1',///,8X,20A4//)
      JN=IN
      INT=0
      IF(JN.GT.0) GO TO 10
      INT=1
      JN=-JN
   10 DO 12 I=1,JN
   12 JOUT(I)=FREQ(I)
      WRITE (6,5) (JOUT(I),I=1,JN)
    5 FORMAT('OFREQUENCY',20I6)
      WRITE (6,7)
    7 FORMAT(' -',128('-'))
C     FIND LARGEST FREQUENCY
```

```
      FMAX=0.
      DO 20 I=1,JN
      IF(FREQ(I).GT.FMAX) FMAX=FREQ(I)
   20 CONTINUE
C     SCALE
      JSCAL=1
      IF(FMAX.GT.60.) JSCAL=(FMAX+59.)/60.
      FSCAL=JSCAL
      DO 50 I=1,JN
   50 JOUT(I)=NOTH
      MAX=FMAX/FSCAL
      DO 80 I=1,MAX
      X=MAX-(I-1)
      DO 70 J=1,JN
      IF(FREQ(J)/FSCAL.GE.X) JOUT(J)=K
   70 CONTINUE
      IX=X*FSCAL
   80 WRITE (6,2) IX,(JOUT(J),J=1,JN)
    2 FORMAT(I6,4X,20(2X,A4))
      WRITE (6,7)
      IF(INT.EQ.1) GO TO 16
      WRITE (6,3) (RANGE(J),J=1,JN)
    3 FORMAT('0INTERVAL',2X,19(F5.1,1X),F5.1//)
      GO TO 15
   16 DO 51 I=1,JN
   51 JOUT(I)=RANGE(I)
      WRITE (6,6) (JOUT(I),I=1,JN)
    6 FORMAT('0INTERVAL',2X,19(I5,1X),I5//)
   15 WRITE (6,1) K,JSCAL
    1 FORMAT('0EACH ',A4,' EQUALS ',I2,' POINTS'/)
      RETURN
      END
```

```
C..........................................................................PLOP0010
C                                                                          PLOP0020
C     SUBROUTINE PLOTP                                                     PLOP0030
C                                                                          PLOP0040
C     PURPOSE                                                              PLOP0050
C                                                                          PLOP0060
C        PRINTS GRAPHS ON THE STANDARD OUTPUT PRINTER. PLOTP ALLOWS FOR    PLOP0070
C     EITHER USER CONTROL OVER SCALING OR AUTOMATIC SCALING AND PRINTS     PLOP0080
C     THE SCALE FACTORS AT THE BOTTOM OF THE GRAPH.                        PLOP0090
C                                                                          PLOP0100
C     CALLING SEQUENCE                                                     PLOP0110
C                                                                          PLOP0120
C        CALL PLOTP(X,Y,N,MODCUR)                                          PLOP0130
C                                                                          PLOP0140
C     DESCRIPTION OF ARGUMENTS                                             PLOP0150
C                                                                          PLOP0160
C     X      VECTOR OF ABSCISSAE (REAL*4)                                  PLOP0170
C                                                                          PLOP0180
C     Y      VECTOR OF ASSOCIATED ORDINATES (REAL*4)                       PLOP0190
C                                                                          PLOP0200
C     N      NUMBER OF (X,Y) PAIRS                                         PLOP0210
C                                                                          PLOP0220
C            WHEN N IS POSITIVE, SCALING IS DONE USING METHOD 1 BELOW      PLOP0230
C            (USER CONTROLLED SCALING)                                     PLOP0240
C                                                                          PLOP0250
C            WHEN N IS NEGATIVE, SCALING IS DONE USING METHOD 2 BELOW      PLOP0260
C            (AUTOMATIC SCALING)                                           PLOP0270
C                                                                          PLOP0280
C     MODCUR CONTROLS THE NUMBER OF CURVES ON ONE GRAPH                    PLOP0290
C            =0 THERE IS ONLY 1 CURVE ON THIS GRAPH                        PLOP0300
C            =1 THIS IS THE FIRST OF TWO OR MORE CURVES ON THIS GRAPH.     PLOP0310
C            =2 THIS IS AN INTERMEDIATE CURVE ON THIS GRAPH                PLOP0320
C            =3 THIS IS THE LAST CURVE ON THIS GRAPH.                      PLOP0330
C                                                                          PLOP0340
C     SCALING                                                              PLOP0350
C                                                                          PLOP0360
C            SCALING IS PERFORMED ONLY ON THE FIRST SET OF POINTS (WHEN    PLOP0370
C        MODCUR = 0 OR 1.) FOR A MULTIPLE CURVE GRAPH, THE USER SHOULD     PLOP0380
C        CALL PLOTP INITIALLY WITH THE LARGEST CURVE TO INSURE OPTIMUM     PLOP0390
C        SCALING.                                                          PLOP0400
C                                                                          PLOP0410
C            AS NOTED IN THE DESCRIPTION OF ARGUMENT N, PLOTP USES TWO     PLOP0420
C        METHODS FOR DETERMINING THE APPROPPRIATE SCALE FACTORS.           PLOP0430
C                                                                          PLOP0440
C     METHOD 1:  PLOTP SCANS THE X AND Y ARRAYS TO DETERMINE THE MAXI-     PLOP0450
C                MUM AND MINIMUM VALUES.  UTPLOT IS THEN CALLED TO PLOT    PLOP0460
C                THE GRAPH.                                                PLOP0470
C                                                                          PLOP0480
```

```
C     METHOD 2:  PLOTP DETERMINES THE MAXIMUM AND MINIMUM VALUES OF X    PLOP0490
C                AND Y AS IN METHOD 1. IF THE MINIMUM IS GREATER THAN    PLOP0500
C                ZERO, IT IS SET TO ZERO, AND IF THE MAXIMUM IS LESS     PLOP0510
C                THAN ZERO IT IS SET TO ZERO. THE MAXIMUM IS THEN        PLOP0520
C                ROUNDED UP TO THE NEXT HIGHEST VALUE CONTAINING 2       PLOP0530
C                SIGNIFICANT FIGUES AND THE MINIMUM IS ROUNDED DOWN TO   PLOP0540
C                THE NEXT LOWEST VALUE CONTAINING 2 SIGNIFICANT FIGURES.PLOP0550
C                A RANGE IS THEN COMPUTED WHICH IS THE DIFFERENCE BE-    PLOP0560
C                TWEEN THE MAXIMUM AND THE MINIMUM. THE RANGE IS AD-     PLOP0570
C                JUSTED UNTIL, IN THE X-DIRECTION, IT IS A MULTIPLE OF   PLOP0580
C                4, AND IN THE Y-DIRECTION, IT IS A MULTIPLE OF 6.       PLOP0590
C                ROUNDED MAXIMUM AND MINIMUMS ARE THEN USED TO CALL      PLOP0600
C                SUBROUTINE UTPLOT WHICH PLOTS THE GRAPH.                PLOP0610
C                                                                        PLOP0620
C           IN EITHER METHOD, EACH PRINT POSITION IN THE X-DIRECTION     PLOP0630
C        WILL BE EQUAL TO (XMAX-XMIN)/80. AND EACH PRINT POSITION IN THEPLOP0640
C        Y-DIRECTION WILL BE EQUAL TO (YMAX-YMIN)/60.                    PLOP0650
C                                                                        PLOP0660
C     GRID LABELLING                                                     PLOP0670
C                                                                        PLOP0680
C           THE DATA TO BE GRAPHED WILL BE FIT INTO AN 80 COLUMN BY      PLOP0690
C        BY 60 ROW GRID. THE GRID WILL BE LABELLED THUSLY:               PLOP0700
C                                                                        PLOP0710
C        IN THE X DIRECTION (COLUMN-WISE), THERE WILL BE 5 VALUES:       PLOP0720
C        THE MAXIMUM, THE MINIMUM, AND 3 INTERMEDIATE AT INCREMENTS OF   PLOP0730
C        (RANGE(2)-RANGE(1))/4. FROM THE MINIMUM.                        PLOP0740
C                                                                        PLOP0750
C        IN THE Y DIRECTION (ROW-WISE) THERE WILL BE 7 VALUES: THE MAXI-PLOP0760
C        MUM, THE MINIMUM, AND 5 INTERMEDIATE AT INCREMENTS OF           PLOP0770
C        (RANGE(4)-RANGE(3))/6. FROM THE MINIMUM.                        PLOP0780
C                                                                        PLOP0790
C        IF THE LABELS HAVE A VALUE BETWEEN 1. AND 10**8, THEY WILL BE   PLOP0800
C        PRINTED IN AN F11.2 FORMAT, OTHERWISE THEY WILL BE PRINTED IN APLOP0810
C        1PE10.3 FORMAT.                                                 PLOP0820
C                                                                        PLOP0830
C     PLOTTING                                                           PLOP0840
C                                                                        PLOP0850
C           FOUR CHARACTERS ARE USED FOR PLOTTING CURVES, ".","+","*",   PLOP0860
C        AND "X". WHEN MORE THAN 4 CURVES ARE PLOTTED THE CHARACTERS     PLOP0870
C        ARE USED REPEATEDLY.  IF A NEW CURVE IS TO BE PLACED IN THE     PLOP0880
C        PLOTTING GRID WHERE AN OLD CURVE EXISTS, THE NEW CURVE REPLACESPLOP0890
C        THE OLD ONE. THUS, IF 3 IDENTICAL CURVES ARE PLOTTED, THEY WILLPLOP0900
C        APPEAR AS ONE CURVE COMPOSED OF "*"'S.                          PLOP0910
C                                                                        PLOP0920
C     MESSAGES                                                           PLOP0930
C                                                                        PLOP0940
C           UNDER CERTAIN CIRCUMSTANCES, A PLOT WILL NOT BE OUTPUT AND   PLOP0950
C        ONE OF THE FOLLOWING MESSAGES WILL BE PRINTED ON THE STANDARD   PLOP0960
```

```
C         OUTPUT IN PLACE OF THE PLOT.
C
C         "ALL Y-VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX & MIN Y
C          WHEN MODCUR=0 OR 1."
C
C         "ALL X VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX AND MIN X
C          WHEN MODCUR=0 OR 1."
C
C         "GRID NOT SETUP WHEN MODCUR LAST 0 OR 1. NO  PLOT UNTIL GRID
C          PROPERLY SETUP."
C
C      NOTE
C
C             THE USER IS EXPECTED TO PROVIDE THE NECESSARY CARRIAGE
C         CONTROLS TO PLACE THE GRAPH PROPERLY ON THE PAGE.  BEFORE
C         CALLING PLOTP THE USER SHOULD ISSUE A PRINT STATEMENT WHICH
C         EJECTS A PAGE SO THAT THE GRAPH WILL BE PLOTTED AT THE TOP
C         OF THE NEXT PAGE. A TITLE CAN BE PRINTED AT THE BOTTOM OF
C         THE GRAPH BY ISSUING A PRINT STATEMENT RIGHT AFTER CALLING
C         THE SUBROUTINE.
C
C.............................................................................
C

      SUBROUTINE PLOTP(X,Y,NN,MODCUR   )
      DIMENSION X( 1), Y( 1), RANGE(4)
      EQUIVALENCE (RANGE(1),XMAX), (RANGE(2),XMIN),(RANGE(3),YMAX),
     1          (RANGE(4),YMIN)
C
      KN=IABS(NN)
      IF(MODCUR.GT.1) GO TO 5
C
C     FIND MAX & MIN FOR SCALE COMPUTATIONS
C
      XMAX=-1.E20
      XMIN=1.E20
      YMAX=-1.E20
      YMIN=1.E20
      DO 1 I=1,KN
      IF(X(I).LT.XMAX) GO TO 6
      XMAX=X(I)
    6 IF(X(I).GT.XMIN) GO TO 7
      XMIN=X(I)
    7 IF(Y(I).LT.YMAX) GO TO 8
      YMAX=Y(I)
    8 IF(Y(I).GT.YMIN) GO TO 1
      YMIN=Y(I)
```

```
    1 CONTINUE
C
C     IF NOT AUTOSCALE GO TO CALL UTPLOT
C
      IF(NN.GT.0) GO TO 5
C
C     COMPUTE X-SCALE & NEW XMAX AND XMIN
C
      CALL PSCALE(XMAX,XMIN,4)
C
C     COMPUTE Y-SCALE & NEW YMAX AND YMIN
C
      CALL PSCALE(YMAX,YMIN,6)
C
C     PLOT CURVE
C
    5 CALL UTPLOT(X,Y,KN,RANGE,1,MODCUR)
      IF(MODCUR. EQ.1.OR.MODCUR.EQ.2) RETURN
C
C     PRINT SCALES WHEN LAST CURVE PLOTTED
C
      XS=(XMAX-XMIN)/80.
      YS=(YMAX-YMIN)/60.
      WRITE(6,100) XS,YS
  100 FORMAT(   15X,'X-SCALE:   "*"=',E10.3,' UNITS'//
     1          15X,'Y-SCALE:   "*"=',E10.3,' UNITS')
      RETURN
      END

      SUBROUTINE PSCALE(XMAX,XMIN,IDIV)
      DIV=IDIV
C     ROUND MAXIMUM TO NEXT HIGHEST 2 SIG FIGS
      XMAX=AMAX1(0.,XMAX)
      CALL ROUND (XMAX,IMX,FMX)
      IMX=IMX-1
      FMX=FMX*10.
    3 XMX=FMX*10.**IMX
      IF(XMX.GE.XMAX) GO TO 2
      FMX=FMX+1.
      IMM=FMX
      FMX=IMM
      GO TO 3
C     ROUND MINIMUM TO NEXT LOWEST 2 SIG FIGS
    2 XMIN=AMIN1(0.,XMIN)
      CALL ROUND (XMIN,IMN,FMN)
      IMN=IMN-1
      FMN=FMN*10.
```

```
   14 XMN=FMN*10.**IMN                                                 PLOP1890
      IF(XMIN.GE.XMN) GO TO 11                                         PLOP1900
      FMN=FMN-1.                                                       PLOP1910
      IMM=FMN                                                          PLOP1920
      FMN=IMM                                                          PLOP1930
      GO TO 14                                                         PLOP1940
C     ROUND MAX & MIN TO 1. OR .1 IF RANGE LARGE                       PLOP1950
   11 XSC=XMX-XMN                                                      PLOP1960
      IM=0                                                             PLOP1970
      SM=1.                                                            PLOP1980
    9 IF(XSC/DIV.LE.SM) GO TO 12                                       PLOP1990
      IF(ABS(XMN).LT.SM.AND.ABS(XMN).GT.0.) XMN=SIGN(SM,XMN)           PLOP2000
      IF(ABS(XMX).LT.SM.AND.ABS(XMX).GT.0.) XMX=SIGN(SM,XMX)           PLOP2010
   12 IF(IM.GT.0) GO TO 19                                             PLOP2020
      SM=.1                                                            PLOP2030
      IM=IM+1                                                          PLOP2040
      GO TO 9                                                          PLOP2050
C     ROUND RANGE (MAX-MIN) TO 2 SIG FIGS                              PLOP2060
   19 XSC=XMX-XMN                                                      PLOP2070
      CALL ROUND (XSC,IS10,FACTX)                                      PLOP2080
C     FIND FACTOR WHICH IS MULTIPLE OF IDIV                            PLOP2090
      FACTX=FACTX*10.                                                  PLOP2100
      OFAC=FACTX                                                       PLOP2110
      IS10=IS10-1                                                      PLOP2120
      IFX=FACTX                                                        PLOP2130
      FACTX=IFX                                                        PLOP2140
   20 IF(MOD(IFX,IDIV).EQ.0.AND.FACTX.GE.OFAC) GO TO 10                PLOP2150
      IFX=IFX+1                                                        PLOP2160
      FACTX=IFX                                                        PLOP2170
      GO TO 20                                                         PLOP2180
   10 IF(IDIV.GT.4) GO TO 15                                           PLOP2190
C     IF X SCALE BETWEEN 8. AND 10., ROUND TO 10.                      PLOP2200
      FFX=ABS(FACTX/10.)                                               PLOP2210
      IF(FFX.GT.8..AND.FFX.LT.10.) FFX=10.                             PLOP2220
      IF(FACT X.LT.0.) FXX=-10.                                        PLOP2230
      FACTX=FFX*10.                                                    PLOP2240
   15 XSC=FACTX*10.**IS10                                              PLOP2250
C     COMPUTE NEW MAX & MIN FROM ROUNDED SCALE                         PLOP2260
      IF(XM N*XM X.NE.0.) GO TO 4                                      PLOP2270
      IF(XM N.LT.0.) XMIN=-XSC                                         PLOP2280
      IF(XM X.GT.0.) XMAX=XSC                                          PLOP2290
      RETURN                                                           PLOP2300
    4 XMAX=XSC+XMN                                                     PLOP2310
      XMIN=XMN                                                         PLOP2320
      RETURN                                                           PLOP2330
      END                                                              PLOP2340
```

```
      SUBROUTINE ROUND(ANUM,IS,FACT)
C
C     EXPRESS ANUM IN SCIENTIFIC NOTATION WHERE
C           ANUM=FACT*10.**IS WHERE FACT IS BETWEEN 1. AND 9.9
C
      IF(ANUM.EQ.0.) GO TO 15
      BNUM=ANUM
      IF(BNUM.LT.0.) BNUM=-BNUM
      IS=ALOG(BNUM)*.43429448
      FACT=BNUM/10.**IS
C     FIND POWER OF 10
      IDD=-3
      R2=0
      DO 10 II=1,5
      IDD=IDD+1
      R1=R2
      R2=10.**(IDD+1)
      IF(FACT.GE.R1.AND.FACT.LT.R2) GO TO 8
   10 CONTINUE
    8 FACT=FACT*10.**(-IDD)
      IS=IS+IDD
C     ROUND MANTISSA TO 2 SIG FIGS
      IFAC=FACT*10.+.05
      FACT=IFAC
      FACT=FACT/10.
      IF(FACT.LT.10.) GO TO 20
C     SET TO 1 IF LESS THAN 10.
      FACT=1.
      IS=IS+1
C     IF INPUT NEGATIVE, SET MANTISSA NEGATIVE
   20 IF(ANUM.LT.0.) FACT=-FACT
      RETURN
C     SET TO 0. IF 0.
   15 FACT=0.
      IS=0
      RETURN
      END
```

```
C.........................................................................
C
C     SUBROUTINE UTPLOT
C
C     PURPOSE
C
C        PRINTS GRAPHS ON THE STANDARD OUTPUT PRINTER
C
C     FEATURES
C
C     1) FULL CONTROL OVER SCALING
C     2) ABILITY TO PLOT SINGLE OR DOUBLE PRECISION VECTORS
C
C     CALLING SEQUENCE
C
C     CALL UTPLOT(X,Y,N,RANGE,K,MODCUR)
C
C     DESCRIPTION OF ARGUMENTS
C
C     X        VECTOR OF ABSCISSAE
C
C     Y        VECTOR OF ASSOCIATED ORDINATES
C
C     N        NUMBER OF (X,Y) PAIRS
C
C     RANGE    4 WORD SCALING VECTOR WHERE
C              RANGE(1)= MAXIMUM X TO BE PLOTTED
C              RANGE(2)= MINIMUM X TO BE PLOTTED
C              RANGE(3)= MAXIMUM Y TO BE PLOTTED
C              RANGE(4)= MINIMUM Y TO BE PLOTTED
C
C              ALL (X,Y) POINTS OUTSIDE THE ABOVE RANGE WILL BE PLOTTED
C              IN THE BORDER OF THE GRAPH.
C
C     K        EVERY KTH ELEMENT OF X & Y WILL BE PLOTTED, E.G.,
C              FOR REAL*4 DATA (SINGLE PRECISION) K=1
C              FOR REAL*8 DATA (DOUBLE PRECISION) K=2.
C
C     MODCUR   CONTROLS THE NUMBER OF CURVES ON ONE GRAPH
C              =0 THERE IS ONLY 1 CURVE ON THIS GRAPH
C              =1 THIS IS THE FIRST OF TWO OR MORE CURVES ON THIS GRAPH
C              =2 THIS IS AN INTERMEDIATE CURVE ON THIS GRAPH
C              =3 THIS IS THE LAST CURVE ON THIS GRAPH
C
C     SCALING
C
C              SCALING IS PERFORMED ONLY ON THE FIRST SET OF POINTS (WHEN
C        MODCUR = 0 OR 1.) ARRAY RANGE IS USED TO SET UP THE SCALE FAC-
```

```
C        TORS AND NEED ONLY BE DEFINED FOR THE FIRST CALL TO UTPLOT.     UTPL0490
C                                                                        UTPL0500
C     GRID LABELLING                                                     UTPL0510
C                                                                        UTPL0520
C           THE DATA TO BE GRAPHED WILL BE FIT INTO AN 80 COLUMN BY      UTPL0530
C        BY 60 ROW GRID. THE GRID WILL BE LABELLED THUSLY:               UTPL0540
C                                                                        UTPL0550
C        IN THE X DIRECTION (COLUMN-WISE), THERE WILL BE 5 VALUES:       UTPL0560
C        THE MAXIMUM, THE MINIMUM, AND 3 INTERMEDIATE AT INCREMENTS OF   UTPL0570
C        (RANGE(2)-RANGE(1))/4. FROM THE MINIMUM.                        UTPL0580
C                                                                        UTPL0590
C        IN THE Y DIRECTION (ROW-WISE) THERE WILL BE 7 VALUES: THE MAXI-UTPL0600
C        MUM, THE MINIMUM, AND 5 INTERMEDIATE AT INCREMENTS OF           UTPL0610
C        (RANGE(4)-RANGE(3))/6. FROM THE MINIMUM.                        UTPL0620
C                                                                        UTPL0630
C        IF THE LABELS HAVE A VALUE BETWEEN 1. AND 10**8, THEY WILL BE   UTPL0640
C        PRINTED IN AN F11.2 FORMAT, OTHERWISE THEY WILL BE PRINTED IN AUTPL0650
C        1PE10.3 FORMAT.                                                 UTPL0660
C                                                                        UTPL0670
C     PLOTTING                                                           UTPL0680
C                                                                        UTPL0690
C           FOUR CHARACTERS ARE USED FOR PLOTTING CURVES, ".","+","*",  UTPL0700
C        AND "X". WHEN MORE THAN 4 CURVES ARE PLOTTED THE CHARACTERS     UTPL0710
C        ARE USED REPEATEDLY.  IF A NEW CURVE IS TO BE PLACED IN THE     UTPL0720
C        PLOTTING GRID WHERE AN OLD CURVE EXISTS, THE NEW CURVE REPLACESUTPL0730
C        THE OLD ONE. THUS, IF 3 IDENTICAL CURVES ARE PLOTTED, THEY WILLUTPL0740
C        APPEAR AS ONE CURVE COMPOSED OF "*"'S.                          UTPL0750
C                                                                        UTPL0760
C     MESSAGES                                                           UTPL0770
C                                                                        UTPL0780
C           UNDER CERTAIN CIRCUMSTANCES, A PLOT WILL NOT BE OUTPUT AND  UTPL0790
C        ONE OF THE FOLLOWING MESSAGES WILL BE PRINTED ON THE STANDARD   UTPL0800
C        OUTPUT IN PLACE OF THE PLOT.                                    UTPL0810
C                                                                        UTPL0820
C        "ALL Y-VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX & MIN Y      UTPL0830
C         WHEN MODCUR=0 OR 1."                                           UTPL0840
C                                                                        UTPL0850
C        "ALL X VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX AND MIN X    UTPL0860
C         WHEN MODCUR=0 OR 1."                                           UTPL0870
C                                                                        UTPL0880
C        "GRID NOT SETUP WHEN MODCUR LAST 0 OR 1. NO PLOT UNTIL GRID     UTPL0890
C         PROPERLY SETUP."                                               UTPL0900
C                                                                        UTPL0910
C     NOTE                                                               UTPL0920
C                                                                        UTPL0930
C           THE USER IS EXPECTED TO PROVIDE THE NECESSARY CARRIAGE       UTPL0940
C        CONTROLS TO PLACE THE GRAPH PROPERLY ON THE PAGE.  BEFORE       UTPL0950
C        CALLING UTPLOT THE USER SHOULD ISSUE A PRINT STATEMENT WHICH    UTPL0960
```

```
C         EJECTS A PAGE SO THAT THE GRAPH WILL BE PLOTTED AT THE TOP
C         OF THE NEXT PAGE. A TITLE CAN BE PRINTED AT THE BOTTOM OF
C         THE GRAPH BY ISSUING A PRINT STATEMENT RIGHT AFTER CALLING
C         THE SUBROUTINE.
C
C.......................................................................
C

      SUBROUTINE UTPLOT (X   ,Y   ,NDATA,RANGE,KKZ,MODCUR)
      DIMENSION GRID(61,81),XSCALE(5),YSCALE(7)
      DIMENSION X   (1),Y   (1),RANGE(4)
      INTEGER*2 GRID,BLANK,DOT,XCHAR(4)/1H.,1H+,1H*,1HX/
      DATA DOT,BLANK/Z4B40,Z4040/
      KDATA=NDATA*KKZ
      IF(MODCUR.GT.1) GO TO 444
C
C     GRID IS THE MATRIX USED TO PLOT THE POINTS
C
      IERR=0
      XMAX=RANGE(1)
      XMIN=RANGE(2)
      YMAX=RANGE(3)
      YMIN=RANGE(4)
C
C     CHECKING X AND Y POINTS AND PLOTTING THOSE OUT OF RANGE
C     AT THE MARGIN
C
      DO 30 I=1,KDATA,KKZ
      IF(X(I).GT.XMAX.OR.X(I).LT.XMIN.OR.Y(I).GT.YMAX.OR.Y(I).LT.YMIN)
     1  IERR=IERR+1
      IF(X(I).LE.XMAX) GO TO 205
      X   (I)=XMAX
      GOTO 210
  205 IF(X(I).GE.XMIN) GO TO 210
      X   (I)=XMIN
  210 IF(Y(I).LE.YMAX) GO TO 215
      Y   (I)=YMAX
      GOTO 30
  215 IF(Y(I).GE.YMIN) GO TO 30
      Y   (I)=YMIN
C
   30 CONTINUE
C
C     PLOTTING X AND Y AXIS , IF NECESSARY
C
      JERR=0
      XRANGE=XMAX-XMIN
```

```
      YRANGE=YMAX-YMIN
      IF (YRANGE.NE.0.)  GO TO 298
      IF(YMIN.EQ.0.) GO TO 889
      YMIN=0.
      YRANGE=YMAX
      GO TO 299
  298 IF (XRANGE.NE.0.)  GO TO 299
      IF(XMIN.EQ.0.) GO TO 887
      XMIN=0.
      XRANGE=XMAX
C
C     BLANKING OUT MATRIX-(GRID)
C
  299 DO 300 I=1,61
      DO 301 JJ=1,81
 301  GRID(I,JJ)=BLANK
  300 CONTINUE
      IF(XMAX*XMIN.GE.0.) GO TO 222
      IYAXIS=80.*(-XMIN)/XRANGE+1.5
      DO 40 I=1,61
   40 GRID(I,IYAXIS)=DOT
  222 IF(YMAX*YMIN.GE.0.) GO TO 333
      IXAXIS=60.*YMAX/YRANGE+1.5
      DO 60 I=1,81
   60 GRID(IXAXIS,I)=DOT
C
C     COMPUTE PROPER SCALE NUMBERS
C
  333 XINCR=XRANGE/4.
      YINCR=YRANGE/6.
      XSCALE(1)=XMAX
      XSCALE(5)=XMIN
      DO 80 I=2,4
      XSCALE(I)=XSCALE(I-1)-XINCR
      IF(ABS(XSCALE(I)).LT.1.E-4) XSCALE(I)=0.
   80 CONTINUE
      YSCALE(1)=YMAX
      YSCALE(7)=YMIN
      DO 81 I=2,6
      YSCALE(I)=YSCALE(I-1)-YINCR
      IF(ABS(YSCALE(I)).LT.1.E-4) YSCALE(I)=0.
   81 CONTINUE
      DO 85 II=1,2
      JJ=6-II
      XT=XSCALE(JJ)
      XSCALE(JJ)=XSCALE(II)
   85 XSCALE(II)=XT
C
```

```
C
C     PLACING POINTS IN THEIR PROPER GRID POSITIONS
C
  444 IF(MODCUR.LT.2) JSET=0
      IF(JERR.GT.0) GO TO 885
      JSET=JSET+1
      IF(JSET.GT.4) JSET=1
      DO 700 I=1,KDATA,KKZ
      IPTX=60.*(YMAX-Y(I))/YRANGE+1.5
      IPTY=80.*(X(I)-XMIN)/XRANGE+1.5
      IF(IPTX.GT.61.OR.IPTY.GT.81) GO TO 70
      IF(IPTX.LE.0.OR.IPTY.LE.0)GO TO 70
      GRID(IPTX,IPTY) = XCHAR(JSET)
      GO TO 700
   70 IERR=IERR+1
  700 CONTINUE
C     OUTPUT SECTION WITH GRAPH
C
      IF(MODCUR.EQ.1.OR.MODCUR.EQ.2) RETURN
      AXR=ABS(XRANGE)
      AYR=ABS(YRANGE)
      IF(AXR.LT.1.E+8.AND.AXR.GE..95) GO TO 400
      WRITE(6,17) XSCALE
   17 FORMAT(12X,1PE10.3,4(10X,E10.3)/15X,'**',8('+*********'),'+**')
      GO TO 401
  400 WRITE(6,117) XSCALE
  117 FORMAT( 8X,F11.2,4( 9X,F11.2)/15X,'**',8('+*********'),'+**')
  401 II=1
      DO 101 IK=1,61
      IF(MOD(IK-1,10).NE.0) GO TO 92
      IF(AYR.LT.1.E+8.AND.AYR.GE..95) GO TO 404
      WRITE(6,18) YSCALE(II),(GRID(IK,IX),IX=1,81),YSCALE(II)
   18 FORMAT(3X,1PE10.3,2X,1H+,1X,81A1,1X,1H+,2X,E10.3)
      GO TO 405
  404 WRITE(6,118) YSCALE(II),(GRID(IK,IX),IX=1,81),YSCALE(II)
  118 FORMAT(2X,F11.2,'  + ',81A1,' +  ',F11.2)
  405 II=II+1
      GO TO 101
   92 WRITE(6,19) (GRID(IK,IX),IX=1,81)
   19 FORMAT(15X,'* ',81A1,' *')
  101 CONTINUE
      IF(AXR.LT.1.E+8.AND.AXR.GE..95) GO TO 402
      WRITE(6,22) XSCALE
   22 FORMAT(15X,'**',8('+*********'),'+**'/12X,1PE10.3,4(10X,E10.3),//)
      GO TO 403
  402 WRITE(6,217) XSCALE
  217 FORMAT(15X,'**',8('+*********'),'+**'/ 8X,F11.2,4( 9X,F11.2),//)
  403 IF(IERR.GT.0) WRITE(6,20) IERR
```

```
 20  FORMAT(10X 'NUMBER OF POINTS OUT OF RANGE ='  I4)                 UTPL2390
1000 RETURN                                                            UTPL2400
C                                                                      UTPL2410
 889 WRITE(6,888)                                                      UTPL2420
 888 FORMAT(' ALL Y VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX & MIN YUTPL2430
    1 WHEN MODCUR=0 OR 1.')                                            UTPL2440
     JERR=10                                                           UTPL2450
     RETURN                                                            UTPL2460
 887 WRITE(6,886)                                                      UTPL2470
 886 FORMAT(' ALL X VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX & MIN XUTPL2480
    1 WHEN MODCUR=0 OR 1.')                                            UTPL2490
     JERR=10                                                           UTPL2500
     RETURN                                                            UTPL2510
 885 WRITE(6,884)                                                      UTPL2520
 884 FORMAT(' GRID NOT SETUP WHEN MODCUR LAST 0 OR 1. NO PLOT UNTIL GRIUTPL2530
    1D PROPERLY SETUP')                                                UTPL2540
     RETURN                                                            UTPL2550
     END                                                               UTPL2560
```

APPENDIX D

TABLES OF CHANNEL SERVICE STATISTICS FOR MAY-JUNF

TABLE XVIII. FASW MAY-JUNE SERVICE STATISTICS

DATE	NR. 1ST RUN MSG	NR. SUBS	NR. SCRND	NR. RERUN	# SCRN REQ	% SCRND	% SCRN	RERUNS/ 1STRUN	SCRNS/ REQ	RERUNS/ REQ	SVC REQ RATE
26 MAY	392.	14.	57.	15.	9.	14.5	26.3	3.8	6.3	1.7	0.0104
27 MAY	337.	13.	70.	16.	7.	20.8	22.9	4.7	10.0	2.3	0.0160
28 MAY	347.	9.	21.	5.	5.	6.1	23.8	1.4	4.2	1.0	0.0067
29 MAY	294.	9.	57.	16.	3.	19.4	28.1	5.4	19.0	5.3	0.0215
30 MAY	176.	6.	16.	8.	2.	9.1	50.0	4.5	8.0	4.0	0.0152
31 MAY	132.	7.	9.	3.	2.	6.8	33.3	2.3	4.5	1.5	0.0097
01 JUN	196.	20.	6.	1.	2.	3.1	16.7	0.5	3.0	0.5	0.0015
02 JUN	398.	17.	14.	7.	2.	3.5	50.0	1.8	7.0	3.5	0.0021
03 JUN	345.	17.	34.	1.	7.	9.9	2.9	0.3	4.9	0.1	0.0058
04 JUN	340.	17.	26.	6.	2.	7.6	23.1	1.8	13.0	3.0	0.0045
05 JUN	324.	15.	11.	5.	2.	3.4	45.5	1.5	5.5	2.5	0.0023
06 JUN	186.	12.	9.	2.	5.	4.8	22.2	1.1	1.8	0.4	0.0040
07 JUN	251.	23.	20.	4.	2.	8.0	20.0	1.6	10.0	2.0	0.0035
08 JUN	386.	26.	17.	2.	5.	4.4	11.8	0.5	3.4	0.4	0.0017
TOTAL	4104.	205.	367.	91.	55.						
AVE	293.1	14.6	26.2	6.5	3.9	8.9	24.8	2.2	6.7	1.7	0.0061

TABLE XIX. FALD MAY-JUNE SERVICE STATISTICS

DATE	NR. RUN	1ST MSG	NR. SUBS	NR. SCRND	NR. RERUN	# SCRN REQ	% SCRND	% SCRN	RERUNS/ 1STRUN	SCRNS/ REQ	RERUNS/ REQ	SVC REQ RATE
26 MAY	267.		18.	47.	25.	3.	17.6	53.2	9.4	15.7	8.3	0.0098
27 MAY	278.		14.	18.	5.	2.	6.5	27.8	1.8	9.0	2.5	0.0046
28 MAY	280.		14.	30.	5.	5.	10.7	16.7	1.8	6.0	1.0	0.0077
29 MAY	238.		10.	21.	7.	1.	8.8	33.3	2.9	21.0	7.0	0.0088
30 MAY	148.		9.	41.	5.	2.	27.7	12.2	3.4	20.5	2.5	0.0308
31 MAY	115.		11.	1.	0.	1.	0.9	0.0	0.0	1.0	0.0	0.0008
01 JUN	168.		22.	34.	7.	3.	20.2	20.6	4.2	11.3	2.3	0.0092
02 JUN	318.		23.	98.	17.	6.	30.8	17.3	5.3	16.3	2.8	0.0134
03 JUN	304.		26.	1.	0.	1.	0.3	0.0	0.0	1.0	0.0	0.0001
04 JUN	327.		26.	26.	4.	4.	8.0	15.4	1.2	6.5	1.0	0.0031
05 JUN	267.		20.	24.	0.	2.	9.0	0.0	0.0	12.0	0.0	0.0045
06 JUN	142.		20.	2.	0.	1.	1.4	0.0	0.0	2.0	0.0	0.0007
07 JUN	220.		30.	2.	0.	1.	0.9	0.0	0.0	2.0	0.0	0.0003
08 JUN	335.		30.	2.	0.	2.	0.6	0.0	0.0	1.0	0.0	0.0002
TOTAL	3407.		273.	347.	75.	34.						
AVE	243.4		19.5	24.8	5.4	2.4	10.2	21.6	2.2	10.2	2.2	0.0052

TABLE XX. FNSC MAY-JUNE SERVICE STATISTICS

DATE	NR. 1ST RUN MSG	NR. SUBS	NR. SCRND	NR. RERUN	# SCRN REQ	% SCRND	% SCRN	RERUNS/ 1STRUN	SCRNS/ REQ	RERUNS/ REQ	SVC REQ RATE
26 MAY	148.	12.	17.	4.	5.	11.5	23.5	2.7	3.4	0.8	0.0096
27 MAY	157.	13.	57.	6.	8.	36.3	10.5	3.8	7.1	0.7	0.0279
28 MAY	180.	13.	25.	4.	5.	13.9	16.0	2.2	5.0	0.8	0.0107
29 MAY	196.	11.	14.	6.	3.	7.1	42.9	3.1	4.7	2.0	0.0065
30 MAY	120.	10.	8.	0.	3.	6.7	0.0	0.0	2.7	0.0	0.0067
31 MAY	107.	9.	42.	10.	5.	39.3	23.8	9.3	8.4	2.0	0.0436
01 JUN	196.	13.	22.	8.	4.	11.2	36.4	4.1	5.5	2.0	0.0086
02 JUN	275.	14.	94.	5.	9.	34.2	5.3	1.8	10.4	0.6	0.0244
03 JUN	241.	12.	46.	10.	8.	19.1	21.7	4.1	5.8	1.2	0.0159
04 JUN	178.	12.	40.	4.	4.	22.5	10.0	2.2	10.0	1.0	0.0187
05 JUN	125.	11.	28.	1.	3.	22.4	3.6	0.8	9.3	0.3	0.0204
06 JUN	106.	11.	26.	4.	2.	24.5	15.4	3.8	13.0	2.0	0.0223
07 JUN	106.	12.	24.	0.	3.	22.6	0.0	0.0	8.0	0.0	0.0189
08 JUN	188.	12.	106.	9.	5.	56.4	8.5	4.8	21.2	1.8	0.0470
TOTAL	2323.	165.	549.	71.	67.						
AVE	165.9	11.8	39.2	5.1	4.8	23.6	12.9	3.1	8.2	1.1	0.0201

TABLE XXI. FRTT MAY-JUNE SERVICE STATISTICS

DATE	NR. RUN	1ST MSG	NR. SUBS	NR. SCRND	NR. RERUN	# SCRN REQ	% SCRND	% SCRN	RERUNS/ 1STRUN	SCRNS/ REQ	RERUNS/ REQ	SVC REQ RATE
26 MAY	140.		12.	40.	1.	5.	28.6	2.5	0.7	8.0	0.2	0.0238
27 MAY	225.		11.	49.	8.	2.	21.8	16.3	3.6	24.5	4.0	0.0198
28 MAY	237.		9.	2.	0.	1.	0.8	0.0	0.0	2.0	0.0	0.0009
29 MAY	338.		8.	5.	5.	2.	1.5	100.0	1.5	2.5	2.5	0.0018
30 MAY	142.		8.	3.	0.	1.	2.1	0.0	0.0	3.0	0.0	0.0026
31 MAY	124.		8.	5.	0.	1.	4.0	0.0	0.0	5.0	0.0	0.0050
01 JUN	158.		9.	3.	0.	1.	1.9	0.0	0.0	3.0	0.0	0.0021
02 JUN	224.		8.	2.	7.	2.	0.9	350.0	3.1	1.0	3.5	0.0011
03 JUN	179.		8.	103.	15.	5.	57.5	14.6	8.4	20.6	3.0	0.0719
04 JUN	106.		6.	45.	6.	6.	42.5	13.3	5.7	7.5	1.0	0.0708
05 JUN	190.		6.	50.	10.	1.	26.3	20.0	5.3	50.0	10.0	0.0439
06 JUN	116.		5.	0.	0.	0.	0.0	0.0	0.0	0.0	0.0	0.0
07 JUN	150.		8.	10.	1.	4.	6.7	10.0	0.7	2.5	0.2	0.0083
08 JUN	208.		7.	2.	0.	2.	1.0	0.0	0.0	1.0	0.0	0.0014
TOTAL	2537.		113.	319.	53.	33.						
AVE	181.2		8.1	22.8	3.8	2.4	12.6	16.6	2.1	9.7	1.6	0.0156

SIMULATION MODEL COMPUTER PROGRAM

```
*    FLEET MULTI-CHANNEL BROADCAST CHANNEL PAIR SIMULATION MODEL
*      OPERATING WITH M/G/1&2 (PREEMPT RERUN) QUEUEING SYSTEM
*      FOR FASW CHANNEL PAIR
*
*    NOTE: CARDS FOR FLASH PREEMPTION ARE MARKED FOR USE WITH THE TWO
*            INDICATED METHODS:
*            *+--PREEMPT RESUME
*            +--PREEMPT RERUN
*
*    NOTE: THE SIMULATION TIME USED IN THIS MODEL IS:
*            1:00 MINUTE REAL TIME=100 SIMULATION TIME UNITS
*            CAUTION: ALL MODIFIERS, TABLE MEANS AND OTHER TIME
*                       STATISTICS IN THE MODEL OR THE OUTPUT SHOULD BE
*                       INTERPRETED ACCORDINGLY (I.E., 784.09 SIMULATED
*                       TIME=7.8409 REAL TIME) THE EXCEPTION IS THAT
*                       FUNCTION MEANS IN THE DOCUMENTATION ARE SHOWN IN
*                       REAL TIME VALUES
*
*    SAVEVALUE IDENTIFICATION:
*
*     FULLWORD SAVEVALUES:
*
*      X1-FIRST RUN MSGS IA MODIFIER
*      X2-SCREEN REQ IA MODIFIER
*      X3-ONE DAYS SIMULATED TIME PERIOD
*
*      X4-HOURLY FIRST RUN MSGS
*      X5-HOURLY RERUN MSGS
*      X6-TOTAL FIRST RUN MSGS TO THE HOUR
*      X7-TOTAL RERUN MSGS TO THE HOUR
*      X11-HOURLY ROUTINE MSGS
*      X12-HOURLY ROUTINE RERUN MSGS
*      X13-HOURLY PRIORITY MSGS
*      X14-HOURLY PRIORITY RERUN MSGS
*      X15-HOURLY IMMEDIATE MSGS
*      X16-HOURLY IMMEDIATE RERUN MSGS
*      X17-HOURLY FLASH MSGS
*      X18-TOTAL ROUTINE MSGS TO THE HOUR
*      X19-TOTAL ROUTINE RERUN MSGS TO THE HOUR
*      X20-TOTAL PRIORITY MSGS TO THE HOUR
*      X21-TOTAL PRIORITY RERUN MSGS TO THE HOUR
*      X22-TOTAL IMMEDIATE MSGS TO THE HOUR
*      X23-TOTAL IMMEDIATE RERUN MSGS TO THE HOUR
*      X24-TOTAL FLASH MSGS TO THE HOUR
```

```
*    HALFWORD SAVEVALUES:
*
*   NOTE: MODIFIERS ARE CHOSEN TO ENSURE OBTAINING AN ACCURATE MEAN VALUE
*         FOR FUNCTION DRAWS (SEE GPSS USER'S MANUAL)
*
*     XH1-ROUTINE MSG LENGTH MODIFIER
*     XH2-PRIORITY MSG LENGTH MODIFIER
*     XH3-IMMEDIATE MSG LENGTH MODIFIER
*     XH4-FLASH MSG LENGTH MODIFIER
*     XH5-SCREEN REQUEST TRANSMISSION DELAY MODIFIER
*     XH6-SERVICE DESK SYSTEM DELAY MODIFIER (INSTA OR BCS)
*     XH7-SERVICE DESK SYSTEM DELAY MODIFIER (OUTSTA OR OTHER NAVCOMMSTA)
*     XH8-PERCENT OF SCREEN REQUESTS HANDLED BY OUTSTA
*     XH9-RERUNS TRANSMISSION DELAY FROM OUTSTA TO BCS MODIFIER
*     XH10-NUMBER OF RERUNS PER SCREEN REQUEST MODIFIER
*
*     XH11-ROUTINE QUEUE LENGTH TEST VALUE FOR OPENING CHAN2
*     XH12-PRIORITY QUEUE LENGTH TEST VALUE FOR OPENING CHAN2
*     XH13-IMMEDIATE QUEUE LENGTH TEST VALUE FOR OPENING CHAN2
*     XH14-FLASH QUEUE LENGTH TEST VALUE FOR OPENING CHAN2
*
*     XH15-TEST VALUE FOR NUMBER OF RERUNS TO CREATE (XH15=-1, ALWAYS)
*
*     XH16-NUMBER OF FIRST RUN MSG ARRIVALS PER DAY TO BE TRANSMITTED
*     XH17-NR SUBSCRIBERS COPYING THE CHANNEL PAIR
*     XH18-AVE NR SCREENS PER REQUEST (CHAN2 CLOSED)
*     XH19-AVE NR SCREENS PER REQUEST (CHAN2 OPEN)
*     XH20-ACTUAL NR FIRST RUN TRANSMITTED PER DAY ON CHAN1 AND CHAN2
*     XH21-ROUTINE QUEUE LENGTH TEST VALUE FOR CLOSING CHAN2
*     XH22-PRIORITY QUEUE LENGTH TEST VALUE FOR CLOSING CHAN2
*     XH23-NR FIRST RUN MSGS TRANS PREVIOUS DAY. USED FOR SCRN REQ CALC.
*     XH24-PREVIOUS HOUR TOTAL OF MESSAGES TRANSMITTED
*
*   DEFINE INITIAL VALUES FOR SAVEVALUES AND LOGIC SWITCHES
*
        INITIAL    X1,288/X2,21354/X3,144000
*
        INITIAL    XH1,100/XH2,97/XH3,105/XH4,109
        INITIAL    XH5,100/XH6,50/XH7,100/XH8,0/XH9,10/XH10,4
*
        INITIAL    XH11,110/XH12,50/XH13,10/XH14,3
*
        INITIAL    XH15,-1
*
        INITIAL    XH16,422/XH17,38/XH18,8/XH19,1
        INITIAL    XH20,422
        INITIAL    XH21,2/XH22,1
        INITIAL    XH23,422
```

```
*
*  NOTE: TO OPERATE MODEL WITH CHAN2 OPEN FOR WHOLE RUN, INCLUDE OR
*         REPLACE THE ABOVE CARDS WITH THE FOLLOWING:
*      INITIAL     LS2  (OPENS CHAN2)
*      INITIAL     XH21,-1/XH22,-1  (PREVENTS CHAN2 FROM CLOSING)
*  NOTE: TO OPERATE MODEL WITH CHAN2 CLOSED FOR WHOLE RUN, REPLACE THE
*         ABOVE CARDS WITH THE FOLLOWING:
*      INITIAL     XH11,1000/XH12,1000/XH13,1000/XH14,1000
*                       (PREVENTS CHAN2 FROM OPENING)
*
*  DEFINE VARIABLES AND FLOATING POINT VARIABLES
*
 1     VARIABLE    Q1+Q2   ADD CURRENT CONTENTS OF QUEUES 1 & 2 FOR TEST
 2     VARIABLE    Q3+Q4   ADD CURRENT CONTENTS OF QUEUES 3 & 4 FOR TEST
 3     VARIABLE    Q5+Q6   ADD CURRENT CONTENTS OF QUEUES 5 & 6 FOR TEST
 4     VARIABLE    3*P1    MULTIPLY FLASH MESSAGE LENGTH BY 3
 5     FVARIABLE   (4436214/100000)+(65/100000)(XH23*XH17)  FASW SCRNS
 6     FVARIABLE   (1549927/100000)+(542/100000)(XH23*XH17) FRTT SCRNS
*  NOTE: GPSS VARIABLES DO NOT ACCEPT DECIMAL OR NEGATIVE NUMBERS, HENCE
*         CALCULATIONS MUST BE PERFORMED AS SHOWN
 7     FVARIABLE   V5/XH18        NR SCRN REQ PER DAY CHAN2 CLOSED
 8     FVARIABLE   V6/XH19        NR SCRN REQ PER DAY CHAN2 OPEN
 9     FVARIABLE   6000/((FN12/10000)*XH16)  HOURLY MEAN IA FOR 1STRUN
10     FVARIABLE   X3/V7          MEAN IA TIME OF SCRN REQS CHAN2 CLOSED
11     FVARIABLE   X3/V8          MEAN IA TIME OF SCRN REQS CHAN2 OPEN
12     VARIABLE    P1-X18                    THESE VARIABLES
13     VARIABLE    P2-X19
14     VARIABLE    P3-X20                       ARE USED
15     VARIABLE    P4-X21
16     VARIABLE    P5-X22                     TO CALCULATE
17     VARIABLE    P6-X23
18     VARIABLE    P7-X24                    HOURLY AND DAILY
19     VARIABLE    P8-X6
20     VARIABLE    P9-X7                        STATISTICS
21     VARIABLE    X4+X5
22     VARIABLE    XH20-XH24                 (SEE STATISTICAL ROUTINE
23     VARIABLE    Q1+Q2+Q3+Q4+Q5+Q6+Q7       AT END OF PROGRAM)
*
*
*  TRANSACTION PARAMETER USE (MESSAGE TRANSACTIONS ONLY):
*   NOTE: IN THE STATISTICAL GATHERING ROUTINE PARAMETERS ARE USED
*         DIFFERENTLY
*
*    P1-CONTAINS MESSAGE LENGTH ASSIGNED
*    P3-USED FOR TABLE REFERENCE IN TABULATING MESSAGE LENGTHS
*    P9-IF PREEMPTED REASSIGNS PREC TO 15 STORES OLD PR IN P9
*    P10-IF PREEMPTED STORES REMAINING MSG LENGTH IN P10
*    P11-NR. RERUNS ASSIGNED TO A SCREEN REQ
```

```
*
*
*  DEFINE STATISTIC TABLES AND MATRICES
*
 1     TABLE      IA,100,100,16    ROUTINE INTERARRIVAL TIMES
 2     TABLE      IA,100,100,16    ROUTINE RERUN INTERARRIVAL TIMES
 3     TABLE      IA,100,100,21    PRIORITY INTERARRIVAL TIMES
 4     TABLE      IA,100,100,21    PRIORITY RERUN INTERARRIVAL TIMES
 5     TABLE      IA,100,100,21    IMMEDIATE INTERARRIVAL TIMES
 6     TABLE      IA,100,100,21    IMMEDIATE RERUN INTERARRIVAL TIMES
 7     TABLE      IA,1000,1000,9   FLASH INTERARRIVAL TIMES
*
 8     TABLE      P1,50,50,21      ROUTINE MESSAGE LENGTHS
 9     TABLE      P1,50,50,21      ROUTINE RERUN MESSAGE LENGTHS
 10    TABLE      P1,50,50,21      PRIORITY MESSAGE LENGTHS
 11    TABLE      P1,50,50,21      PRIORITY RERUN MESSAGE LENGTHS
 12    TABLE      P1,50,50,21      IMMEDIATE MESSAGE LENGTHS
 13    TABLE      P1,50,50,21      IMMEDIATE RERUN MESSAGE LENGTHS
 14    TABLE      P1,50,50,21      FLASH MESSAGE LENGTHS
*
 15    TABLE      IA,100,100,21    SCREEN REQUEST INTERARRIVAL TIMES
*
 1     MATRIX     X,20,2       OPENING AND CLOSING TIMES OF CHAN2
 1     MATRIX     H,97,12      HOURLY STATISTICS OF ARRIVALS(FIRST RUN,
*                                RERUN,TOTAL), TRANSMISSIONS(TOTAL) AND
*                                BACKLOGS(BY PRECEDENCES AND TOTAL)
*
*  DEFINE FUNCTIONS
*
 1     FUNCTION   RN2,C31      IA TIMES(FIRST RUN & SCRN REQ) (EXP-MU=1)
0,0/.049,.05/.1,.104/.139,.15/.2,.222/.258,.3/.3,.355/.33,.4/.4,.509/
.451,.61/.5,.69/.551,.8/.6,.915/.632,1/.7,1.2/.75,1.38/.8,1.6/.84,1.86/
.88,2.12/.9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2/.97,3.5/.98,3.9/
.99,4.6/.995,5.3/.998,6.2/.999,7.0/.9997,8.0
*
*
 2     FUNCTION   RN3,D4       PREC ASGN FIRST RUN (FASW 13-16 SEP)
.403,1/.760,3/.985,5/1,7
*
*
 3     FUNCTION   RN3,D4       PREC ASGN RERUN FROM INSTA (FASW 13-16 SEP)
.403,2/.760,4/.985,6/1,7
*
*
 4     FUNCTION   RN3,D4       PREC ASGN RERUN FROM OUTSTA(FASW 13-16 SEP)
.403,1/.760,3/.985,5/1,7
*
*
```

```
 5       FUNCTION    RN5,C54     FASW (R) MSG LGTH (HYPEREXP-R.S.-MU=182.56)
.0000     .25 .1135    .40 .1480    .45 .1811    .50 .2126    .55 .2428    .60
.2717     .65 .2993    .70 .3257    .75 .3509    .80 .3751    .85 .3982    .90
.4203     .95 .4415   1.00 .4618   1.05 .4812   1.10 .4997   1.15 .5175   1.20
.5509    1.30 .5665   1.35 .5815   1.40 .5958   1.45 .6096   1.50 .6227   1.55
.6354    1.60 .6475   1.65 .6591   1.70 .6810   1.80 .7011   1.90 .7283   2.05
.7448    2.15 .7599   2.25 .7671   2.30 .7805   2.40 .7930   2.50 .8100   2.65
.8153    2.70 .8252   2.80 .8299   2.85 .8471   3.05 .8548   3.15 .8620   3.25
.8964    3.85 .9304   4.80 .9392   5.15 .9403   5.20 .9435   5.35 .9759   7.90
.9866    9.80 .9881  10.20 .9883  10.25 .9971  14.90 .9990  15.65 .9999  20.00
*
 6       FUNCTION    RN5,C77     FASW (P) MSG LGTH (HYPEREXP-R.S.-MU=257.33)
.0000     .50 .0318    .55 .0624    .60 .0920    .65 .1205    .70 .1479    .75
.1745     .80 .2000    .85 .2247    .90 .2485    .95 .2714   1.00 .2936   1.05
.3149    1.10 .3356   1.15 .3555   1.20 .3746   1.25 .3932   1.30 .4111   1.35
.4283    1.40 .4450   1.45 .4611   1.50 .4766   1.55 .4916   1.60 .5200   1.70
.5335    1.75 .5466   1.80 .5592   1.85 .5713   1.90 .5831   1.95 .6054   2.05
.6160    2.10 .6263   2.15 .6457   2.25 .6726   2.40 .6810   2.45 .6891   2.50
.6969    2.55 .7045   2.60 .7189   2.70 .7511   2.95 .7625   3.05 .7680   3.10
.7785    3.20 .7929   3.35 .7975   3.40 .8219   3.70 .8256   3.75 .8326   3.85
.8360    3.90 .8424   4.00 .8741   4.60 .8785   4.70 .8826   4.80 .8865   4.90
.9004    5.30 .9035   5.40 .9118   5.70 .9214   6.10 .9276   6.40 .9295   6.50
.9395    7.10 .9403   7.15 .9410   7.20 .9431   7.35 .9534   8.20 .9695  10.15
.9707   10.35 .9741  10.95 .9747  11.05 .9778  11.70 .9812  12.50 .9821  12.75
.9830   13.00 .9857  13.85 .9862  14.05 .9900  15.05 .9999  20.00
*
 7       FUNCTION    RN6,C40     FASW (O) MSG LGTH (HYPEREXP-R.S.-MU=245.27)
.0000     .25 .0254    .30 .1636    .60 .1845    .65 .2048    .70 .2245    .75
.2437     .80 .2806    .90 .2983    .95 .3155   1.00 .3644   1.15 .3798   1.20
.3948    1.25 .4237   1.35 .4510   1.45 .4641   1.50 .5246   1.75 .5358   1.80
.5573    1.90 .5776   2.00 .6062   2.15 .6152   2.20 .6326   2.30 .6410   2.35
.6491    2.40 .6571   2.45 .6648   2.50 .6869   2.65 .6938   2.70 .7073   2.80
.7137    2.85 .7262   2.95 .9019   5.45 .9090   5.65 .9562   7.70 .9680   8.65
.9884   11.90 .9890  12.05 .9900  12.10 .9999  20.00
*
 8       FUNCTION    RN6,C16     FASW-FNSC (COMB) (Z) MSG LGTH(EMP-MU=89.21)
0        .40    .0526 .40    .1053 .70    .2105 .70    .2632 .75    .3158 .75
.3684    .80    .4211 .85    .6316 .85    .6842 .90    .7368 .95    .7895 .95
.8421   1.05    .8947 1.15   .9474 1.25   .9999 1.65
*
 9       FUNCTION    RN7,C52     SCREEN REQ TRANS DELAY (RT.SHFT.EXP-MU=120)
.0         3.0.0500     9.2.1000    15.6.1500    22.5.2000    29.8.2500    37.5
.3000     45.8.3500    54.7.4000    64.3.4500    74.7.5000    86.2.5500    98.8
.5800    107.1.6100   116.0.6400   125.6.6700   136.0.7000   147.5.7200   155.8
.7400    164.6.7600   174.3.7800   184.7.8000   196.1.8200   208.8.8300   215.6
.8400    222.9.8500   230.7.8600   238.9.8700   247.8.8800   257.4.8900   267.9
.8950    273.5.9000   279.3.9050   285.5.9100   292.0.9150   298.8.9200   306.1
.9250    313.8.9300   322.1.9350   331.0.9400   340.6.9450   351.0.9500   362.5
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.9550  375.1.9600  389.3.9650  405.3.9700  423.8.9750  445.7.9800  472.4
.9850  507.0.9900  555.6.9950  638.8.9999 1015.0
*
 10     FUNCTION    RN7,C70     SVC DESK SYS DELAY(HYPEREXP-R.S.-MU=158.77)
.0000 2.0    .0081 2.0    .0626 10.0   .1347 20.0   .1484 22.0   .2069 31.0
.2492 38.0   .2834 44.0   .3211 51.0   .3758 62.0   .4211 72.0   .4586 81.0
.5006 92.0   .5643 111.0 .5939 121.0 .6211 131.0 .6460 141.0 .6690 151.0
.6901 161.0 .7096 171.0 .7275 181.0 .7441 191.0 .7579 200.0 .7735 211.0
.7853 220.0 .7975 230.0 .8109 242.0 .8251 256.0 .8344 266.0 .8388 271.0
.8464 280.0 .8542 290.0 .8622 301.0 .8877 343.0 .8943 356.0 .9012 371.0
.9064 383.0 .9100 392.0 .9111 395.0 .9159 408.0 .9187 416.0 .9230 429.0
.9254 437.0 .9343 469.0 .9370 480.0 .9389 488.0 .9418 501.0 .9440 511.0
.9499 542.0 .9571 586.0 .9582 593.0 .9596 603.0 .9626 626.0 .9643 640.0
.9649 645.0 .9694 686.0 .9705 698.0 .9710 703.0 .9730 725.0 .9735 731.0
.9791 805.0 .9795 811.0 .9802 822.0 .9805 827.0 .9874 969.0 .9876 974.0
.9888 1005.0.9907 1066.0.9945 1236.0.9999 1406.0
*
 11     FUNCTION    RN8,C31     RERUNS PER SCREEN REQUEST (EXP-MU=1)
0,0/.049,.05/.1,.104/.139,.15/.2,.222/.258,.3/.3,.355/.33,.4/.4,.509/
.451,.61/.5,.69/.551,.8/.6,.915/.632,1/.7,1.2/.75,1.38/.8,1.6/.84,1.86/
.88,2.12/.9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2/.97,3.5/.98,3.9/
.99,4.6/.995,5.3/.998,6.2/.999,7.0/.9997,8.0
*
 12     FUNCTION    C1,D96      ARRIVALS DIURNAL FUNCT (FASW 13-16 SEP)
6000   213     12000 498     18000 95      24000 284     30000 213     36000 237
42000 261     48000 284     54000 379     60000 474     66000 118     72000 450
78000 308     84000 569     90000 308     96000 403     102000521     108000735
114000332     120000806     126000450     132000592     138000758     144000712
150000314     156000359     162000195     168000554     174000434     180000749
186000569     192000793     198000150     204000479     210000314     216000210
222000464     228000150     234000359     240000359     246000240     252000479
258000344     264000569     270000464     276000509     282000464     288000479
294000318     300000702     306000552     312000669     318000401     324000485
330000719     336000502     342000385     348000217     354000117     360000385
366000268     372000167     378000351     384000552     390000334     396000301
402000435     408000486     414000518     420000401     426000334     432000401
438000688     444000792     450000563     456000458     462000354     468000271
474000313     480000416     486000395     492000416     498000395     504000250
510000188     516000208     522000375     528000313     534000375     540000292
546000229     552000604     558000438     564000583     570000563     576000521
*
*
 13     FUNCTION    C1,D4       FIRST RUN MSG ARRIVALS/DAY(FASW 13-16 SEP)
144000422     288000668     432000598     576000480
*
*
 14     FUNCTION    C1,D4       NR OF SUBSCRIBERS/DAY (FASW 13-16 SEP)
14400038      28800040      43200040      57600033
```

```
*
* * * * * * * * * * * * START OF THE SIMULATION PROGRAM * * * * * * * *
*
*
*  FIRST RUN MESSAGE GENERATOR WITH PRECEDENCE ASSIGNMENT
*
      GENERATE    X1,FN1                 GENERATE FIRST RUN MESSAGES
 FRUN PRIORITY    FN2                    ASSIGN PRECEDENCE TO EACH MESSAGE
      TABULATE    PR                     TABLE INTERARRIVAL TIMES BY PREC
      ASSIGN      3,PR                   PUT PREC IN PARAMETER 3 (P3) THEN
      ASSIGN      3+,7                    ADD 7 FOR LATER TABULATION USE
*
 SORT TEST G      PR,K1,ASGN1               SORT     |ROUTINE FIRST RUN
      TEST G      PR,K2,ASGN2                AND     |ROUTINE RERUNS
      TEST G      PR,K3,ASGN3               ROUTE    |PRIORITY FIRST RUN
      TEST G      PR,K4,ASGN4             MESSAGES   |PRIORITY RERUNS
      TEST G      PR,K5,ASGN5                TO      |IMMEDIATE FIRST RUN
      TEST G      PR,K6,ASGN6            APPROPRIATE |IMMEDIATE RERUNS
      TRANSFER    ,ASGN7                 QUEUES FOR  |FLASH FIRST RUN/RERUN
*
*  FLASH MESSAGES (PREEMPT ROUTINE)
*
 ASGN7 ASSIGN     1,XH4,8                ASSIGN FLASH MESSAGE LENGTHS
      TABULATE    P3                     TABLE FLASH MESSAGE LENGTHS
      QUEUE       7                      FLASH MESSAGE QUEUE
*
*  ADD A 25 WORD HEADER TO FLASH MSGS AND RERUN 3 TIMES
*
      ASSIGN      1+,25                  ADD A 25 WORD HEADER TO A FLASH
      ASSIGN      1,V4                    MSG, MULTIPLY TOTAL LENGTH BY 3
      TEST L      Q7,XH14,CKCH2     *+   TEST FLASH QUEUE TO CK CHAN2 OPEN
 TRPRE TRANSFER   BOTH,PCHN1,PCHN2  *+   PREEMPT CHAN1 OR CHAN2 (IF OPEN)
*
 CKCH2 GATE LR    2,TRPRE           *+   IF CHAN2 IS OPEN SEND MSG TO
      SPLIT       1,OPTMR           *+   TRPRE,IF NOT START OPTMR AND THEN
      TRANSFER    ,TRPRE            *+   SEND MSG TO BE TRANSMITTED(TRPRE)
*
 PCHN1 PREEMPT    1,PR,PRERR,10,RE *-W/O FLDS C,D,E  +-FLDS A-E
*                                        PREEMPT CHAN1 OF A LESSER PR AND
*                                        TRANSFER PREEMPTED MSG TO PRERR,
*                                        STORE REMAINING TRANSMISSION TIME
*                                        IN P10,REMOVE(RE) MSG FROM CHAN1
      DEPART      PR                *+   DEPART FLASH QUEUE
      ADVANCE     P1                *+   TRANSMIT FLASH MSG (3 TIMES)
      RETURN      1                 *+   TRANSMISSION COMPLETE ON CHAN1
      LOGIC R     1                  +   OPEN MAIN CHAN1 AND CHAN2 GATE 1
      SAVEVALUE   20+,K1,H               COUNT THE NR MSGS TRANSMITTED
      TRANSFER    ,TERM1            *+   TERMINATE MSG FROM SYSTEM
```

```
*
 PCHN2 GATE LS     2                  *+  IF CHAN2 OPEN PREEMPT
       PREEMPT     2,PR,PRERR,10,RE   *-W/O FLDS C,D,E +-FLDS A-E SEE CHAN1
       DEPART      PR                 *+  DEPART FLASH QUEUE
       ADVANCE     P1                 *+  TRANSMIT FLASH MSG (3 TIMES)
       RETURN      2                  *+  TRANSMISSION COMPLETE ON CHAN2
       SAVEVALUE   20+,K1,H               COUNT THE NR MSGS TRANSMITTED
       GATE LS     2,TERM2             +  IF CHAN2 IS OPEN THEN OPEN MAIN
       LOGIC R     1                   +  GATE 1 FOR NEXT MSG, OTHERWISE
       TRANSFER    ,TERM2             *+  TERMINATE MSG FROM SYSTEM
*
*  IMMEDIATE RERUN MESSAGES.
*
 ASGN6 ASSIGN      1,XH3,7                ASSIGN IMMEDIATE RERUN MSG LENGTH
       TABULATE    P3                     TABLE IMMEDIATE RERUN MSG LENGTH
       QUEUE       6                      IMMEDIATE RERUN QUEUE
       TRANSFER    ,TEST1                 GO TO TEST FOR CHAN2 ACTIVATION
*
* IMMEDIATE MESSAGES.
*
 ASGN5 ASSIGN      1,XH3,7                ASSIGN IMMEDIATE MESSAGE LENGTH
       TABULATE    P3                     TABLE IMMEDIATE MESSAGE LENGTH
       QUEUE       5                      IMMEDIATE QUEUE
       TRANSFER    ,TEST1                 GO TO TEST FOR CHAN2 ACTIVATION
*
*  PRIORITY RERUN MESSAGES.
*
 ASGN4 ASSIGN      1,XH2,6                ASSIGN PRIORITY RERUN MSG LENGTH
       TABULATE    P3                     TABLE PRIORITY RERUN MESSAGE LENGTH
       QUEUE       4                      PRIORITY RERUN QUEUE
       TRANSFER    ,TEST1                 GO TO TEST FOR CHAN2 ACTIVATION
*
* PRIORITY MESSAGES.
*
 ASGN3 ASSIGN      1,XH2,6                ASSIGN PRIORITY MESSAGE LENGTH
       TABULATE    P3                     TABLE PRIORITY MESSAGE MENGTH
       QUEUE       3                      PRIORITY QUEUE
       TRANSFER    ,TEST1                 GO TO TEST FOR CHAN2 ACTIVATION
*
*  ROUTINE RERUN MESSAGES.
*
 ASGN2 ASSIGN      1,XH1,5                ASSIGN ROUTINE RERUN MSG LENGTH
       TABULATE    P3                     TABLE ROUTINE RERUN MSG LENGTHS
       QUEUE       2                      ROUTINE RERUN QUEUE
       TRANSFER    ,TEST1                 GO TO TEST FOR CHAN2 ACTIVATION
*
*
*
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*
* ROUTINE MESSAGES.
*
 ASGN1 ASSIGN     1,XH1,5                ASSIGN ROUTINE MESSAGE LENGTH
       TABULATE   P3                     TABLE ROUTINE MESSAGE LENGTHS
       QUEUE      1                      ROUTINE QUEUE
       TRANSFER   ,TEST1                 GO TO TEST FOR CHAN2 ACTIVATION
*
* TESTING SERIES FOR CHAN2 ACTIVATION.
*
 TEST1 GATE LR    2,BUFF1                IF CHAN2 OPEN BRANCH AROUND TEST1
       TEST L     V1,XH11,SPLT1          IF QUEUE 1+2 GE XH11|THEN CHAN2
       TEST L     V2,XH12,SPLT1          IF QUEUE 3+4 GE XH12|WILL BE OPEN
       TEST L     V3,XH13,SPLT1          IF QUEUE 5+6 GE XH13|BY OPTMR
*
 BUFF1 BUFFER                            BUFFER AND GATE 1 ENSURE ONLY 1
       GATE LR    1                      MSG AT A TIME GOES TO CHAN 1 OR 2
       TRANSFER   BOTH,CHAN1,CHAN2       MSG ROUTED TO AVAIL CHANNEL
*
 SPLT1 SPLIT      1,OPTMR                MSG IS SPLIT. PARENT MSG GOES ON
*                                        FOR TRANS,OFFSPRING STARTS OPTMR
       TRANSFER   ,BUFF1                 PARENT MSG IS ROUTED TO BUFF1
*
* TIMER FOR ACTIVATION OF CHAN2.
*
 OPTMR GATE LR    3,TERM3                GATE ALLOWS ONLY 1 XACT IN TIMER
       LOGIC S    3                      AT A TIME. LOGIC SET CLOSES GATE
       PRIORITY   21                     RAISE PR SO CHAN2 WILL OPEN AS
*                                        SOON AS TIMER ALLOWS AND BEFORE A
*                                        MESSAGE LEAVES BUFFER
       ADVANCE    3000                   TIMER (HOLDS XACT 30 MINUTES)
 LOGS2 LOGIC S    2                      OPEN CHAN2 FOR MESSAGES
       LOGIC R    1                      OPEN MAIN GATE1 ON BOTH CHANNELS
       SAVEVALUE  2,V11                  CHAN2 OPEN CHG SCRN REQ IA RATE
       PRINT      ,,C                    PRINT SIMULATION CLOCK TIME
       PRINT      1,3,X                  PRINT VALUES OF X1-X3
       PRINT      1,7,Q                  PRINT QUEUE STATISTICS
       MSAVEVALUE 1,N$LOGS2,1,C1         SAVE OPENING TIME IN MATRIX 1
       LOGIC R    3                      OPEN OPTMR GATE
 TERM3 TERMINATE  0                      TERMINATE TIMER XACT
*
* CHANNEL 1.
*
 CHAN1 SEIZE      1                      MESSAGE SEIZES CHAN1 FACILITY
       LOGIC S    1                      CLOSE MAIN GATE 1
       GATE LR    2,CKUSE                IF GATE 2 IS OPEN GO TO CKUSE
 TESTP TEST E     P10,K0,PRI1        *-ADV1 +-PRI1 TEST IF MSG HAS BEEN
*                                        PREEMPTED. IF SO GO TO PRI1
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        DEPART     PR                         MESSAGE DEPARTS APPROPRIATE QUEUE
 ADV1   ADVANCE    P1                         HOLD MSG FOR DURATION OF MSG
*                                             LENGTH. SIMULATES TRANSMISSION
        RELEASE    1                          TRANSMISSION COMPLETE ON CHAN1
        LOGIC R    1                          OPEN MAIN GATE 1 FOR NEXT MSG
        SAVEVALUE  20+,K1,H                   COUNTS NR MSGS TRANSMITTED
 TERM1  TERMINATE  0                          TERMINATE MSG FROM SYSTEM
*
*  ENSURE GATE 1 IS OPEN WHEN GATE 2 IS OPEN AND CHAN2 IS NOT IN USE
*
 CKUSE  GATE U     2,OPGE1                    IF CHAN2 NOT IN USE GO TO OPGE1
        TRANSFER   ,TESTP                     IF CHAN2 IN USE GO TO TESTP
*
 OPGE1  LOGIC R    1                          OPEN MAIN GATE 1 TO ALLOW ANOTHER
        TRANSFER   ,TESTP                     MSG THRU. THEN MSG GOES TO TESTP
*
*  PREEMPTED MSG IS PUT AT HEAD OF LINE FOR RERUN.    +
*
 PRERR  ASSIGN     9,PR                     + PUT PR IN P9 THEN REASSIGN PR=15
        PRIORITY   15                       + WHICH  PUTS PREEMPTED AT HEAD OF
        TRANSFER   ,BUFF1                   + THE LINE AT THE BUFFER (BUFF1)
*
 PRI1   PRIORITY   P9                       + FOR PREEMPTED MSG IN CHAN1
        TRANSFER   ,ADV1                    + REASSIGN ORIG PR(PR=P9)GO TO ADV1
*
 PRI2   PRIORITY   P9                       + FOR PREEMPTED MSG IN CHAN2
        TRANSFER   ,ADV2                    + REASSIGN ORIG PR(PR=P9)GO TO ADV2
*
*  CHANNEL 2.  NOTE: IF LR2-CHAN2 IS CLOSED AND IF LS2-CHAN2 IS OPEN
*
 CHAN2  GATE LS    2                          CONTROLS IF CHAN2 OPEN FOR
*                                             FIRST RUN TRAFFIC
        SEIZE      2                          MESSAGE SEIZES CHAN2 FACILITY
        LOGIC S    1                          CLOSE MAIN GATE 1
        TEST E     P10,K0,PRI2              *-ADV2 +-PRI2 (SEE CHAN1 EXPLANATION)
        DEPART     PR                         MESSAGE DEPARTS APPROPRIATE QUEUE
        SPLIT      1,TEST2                    SPLIT XACT & TEST IF CHAN2 CLOSES
 ADV2   ADVANCE    P1                         SIMULATE MESSAGE TRANSMISSION
        RELEASE    2                          TRANSMISSION COMPLETE REL CHAN2
        GATE LS    2,TERM2                    IF CHAN2 HAS BEEN CLOSED DO NOT
        LOGIC R    1                          OPEN MAIN GATE, OTHERWISE DO SO
        SAVEVALUE  20+,K1,H                   COUNTS NR MSGS TRANSMITTED
 TERM2  TERMINATE  0                          TERMINATE MSG FROM SYSTEM
*
* TESTING SERIES FOR CHAN2 SHUTDOWN.
*
 TEST2  TEST L     V2,XH22,TERM4              IF QUEUE 3+4 LESS THAN XH22|CLOSE
        TEST L     V1,XH21,TERM4              IF QUEUE 1+2 LESS THAN XH21|CHAN2
```

```
*
* TIMER FOR CHAN2 SHUTDOWN.
*
CLTMR GATE LR     4,TERM4                 GATE ALLOWS ONLY 1 XACT IN TIMER
      LOGIC S     4                       AT A TIME. LOGIC SET CLOSES GATE
      PRIORITY    20                      RAISE PR SO CHAN2 WILL CLOSE
*                                         BEFORE ANOTHER MSG ENTERS. CHAN2
      ADVANCE     P1                      TIMER=MSG LENGTH OF MSG IN CHAN2
LOGR2 LOGIC R     2                       CLOSE CHAN2 FOR FIRST RUN MSGS
      SAVEVALUE   2,V10                   CHAN2 CLOSED CHG SCRN REQ IA RATE
      PRINT       ,,C                     PRINT SIMULATION CLOCK TIME
      PRINT       1,3,X                   PRINT VALUES OF X1-X3
      PRINT       1,7,Q                   PRINT QUEUE STATISTICS
      MSAVEVALUE  1,N$LOGR2,2,C1          SAVE CLOSING TIME IN MATRIX 1
      LOGIC R     4                       OPEN CLTMR GATE FOR NEXT XACT
      GATE U      1,TERM4                 IF CHAN1 IS IN USE AT CLOSING DO
      LOGIC S     1                       NOT OPEN GATE 1,OTHERWISE DO SO
TERM4 TERMINATE   0                       TERMINATE TIMER XACT
*
*  SCREEN REQUEST AND FEEDBACK LOOP ROUTINE
*
      GENERATE    X2,FN1                  GENERATE SCRN REQ MSGS
      TABULATE    15                      TABLE SCRN REQ INTERARRIVAL TIMES
      ADVANCE     XH5,FN9                 SIMULATE DELAY IN TRANSMISSION
      TRANSFER    .XH8,INSTA,OUTST        REQ IS SENT TO BCS OR OTHER NCSTA
*
INSTA ADVANCE     XH6,FN10                SVC DESK SYSTEM PROCESSING TIME
      ASSIGN      11,XH10,11              ASSIGN NR RERUNS TO REQ IN P11
      ASSIGN      11-,1                   SUBTRACT 1 FROM RERUNS FOR SPLIT
      TEST G      P11,XH15,TERM5          IF NR RERUNS=0 TERMINATE REQUEST
      SPLIT       P11,PREC1               CREATE RERUN MSGS IF P11 GT 1
PREC1 PRIORITY    FN3                     ASSIGN PR TO RERUN MESSAGES
      TABULATE    PR                      TABLE INTERARRIVAL TIMES BY PREC
      ASSIGN      3,PR                    PUT PREC IN PARAMETER 3 (P3) THEN
      ASSIGN      3+,7                     ADD 7 FOR LATER TABLUATION USE
      TRANSFER    ,SORT                   RERUN IS ASSIGNED TO QUEUE
*
OUTST ADVANCE     XH7,FN10                OUTSTA SVC DESK SYSTEM PROC TIME
      ASSIGN      11,XH10,11              |
      ASSIGN      11-,1                    |
      TEST G      P11,XH15,TERM6           >--(SEE INSTA COMMENTS)
      SPLIT       P11,PREC2                |
PREC2 PRIORITY    FN4                     |
      ADVANCE     XH9,FN9                 SIMULATE AUTODIN TRANS TO BCS
      TABULATE    PR                      |
      ASSIGN      3,PR                     >--(SEE INSTA COMMENTS)
      ASSIGN      3+,7                    |
      TRANSFER    ,SORT                   RERUN IS ASSIGNED TO QUEUE
```

```
 TERM5 TERMINATE  0                         TERMINATE SCRN REQ IF NO RERUNS
 TERM6 TERMINATE  0                         TERMINATE SCRN REQ IF NO RERUNS
*
*
*
*
*  HOURLY STATISTICAL GATHERING ROUTINE
*                AND
*  FIRST RUN MEAN INTERARRIVAL TIME CALCULATION
*
       GENERATE   6000,,1,97 STARTING AT REAL TIME .01 AND HOURLY THERE-
*                            AFTER DETERMINE FIRST RUN MEAN IA TIME AND
*                            COLLECT STATISTICS
*
 TIME  SAVEVALUE  16,FN13,H  DETERMINE NR FIRST RUN MSG FM FN13 PUT IN
       SAVEVALUE  1,V9       XH16 THEN CALCULATE MEAN IA USING V9
*
        ASSIGN    1,N$ASGN1  R   |STORE IN THE RESPECTIVE PARAMETERS
        ASSIGN    2,N$ASGN2  RRR |
        ASSIGN    3,N$ASGN3  P   |  THE NUMBER OF TOTAL ARRIVALS
        ASSIGN    4,N$ASGN4  PRR |
        ASSIGN    5,N$ASGN5  O   |        TO THE HOUR BY
        ASSIGN    6,N$ASGN6  ORR |
        ASSIGN    7,N$ASGN7  Z   |          PRECEDENCE
        ASSIGN    8,N$FRUN   TOTAL NUMBER FIRST RUN ARRIVALS TO THE HOUR
        ASSIGN    9,N$PREC1  TOTAL NUMBER OF
        ASSIGN    9+,N$PREC2   RERUN ARRIVALS TO THE HOUR
*
       SAVEVALUE  4,V19      CALCULATE NR OF 1STRUN ARRIVALS IN LAST HR
       SAVEVALUE  5,V20      CALCULATE NR OF RERUN ARRIVALS IN LAST HOUR
*
       SAVEVALUE  11,V12     R   |CALCULATE NUMBER OF ARRIVALS
       SAVEVALUE  12,V13     RRR |
       SAVEVALUE  13,V14     P   |
       SAVEVALUE  14,V15     PRR |      IN THE LAST HOUR
       SAVEVALUE  15,V16     O   |
       SAVEVALUE  16,V17     ORR |
       SAVEVALUE  17,V18     Z   |        BY PRECEDENCE
*
       SAVEVALUE  6,P8       STORE
       SAVEVALUE  7,P9
       SAVEVALUE  18,P1         THE RESPECTIVE
       SAVEVALUE  19,P2
       SAVEVALUE  20,P3            TOTALS TO THE HOUR
       SAVEVALUE  21,P4
       SAVEVALUE  22,P5               IN SAVEVALUES
       SAVEVALUE  23,P6
       SAVEVALUE  24,P7                  X6-X7 AND X18-X24
```

```
*
*
*
      MSAVEVALUE 1,N$TIME,1,X4,H      COL 1--1STRUN ARR LAST HR  |M
      MSAVEVALUE 1,N$TIME,2,X5,H          2--RERUN ARR LAST HR   | A
      MSAVEVALUE 1,N$TIME,3,V21,H         3--TOTAL ARR LAST HR   |  T
      MSAVEVALUE 1,N$TIME,4,V22,H         4--TOTAL TRANS LAST HR |   R
      MSAVEVALUE 1,N$TIME,5,Q7,H          5--Z       CURRENT     |C   I
      MSAVEVALUE 1,N$TIME,6,Q6,H          6--ORR      QUEUE      | O   X
      MSAVEVALUE 1,N$TIME,7,Q5,H          7--O     CONTENTS      |  N    1
      MSAVEVALUE 1,N$TIME,8,Q4,H          8--PRR   (BACKLOG)     |   T
      MSAVEVALUE 1,N$TIME,9,Q3,H          9--P       BY PREC     |    E
      MSAVEVALUE 1,N$TIME,10,Q2,H         10-RRR     AT END      |     N
      MSAVEVALUE 1,N$TIME,11,Q1,H         11-R       OF HOUR     |      T
      MSAVEVALUE 1,N$TIME,12,V23,H        12-    TOTAL BACKLOG   |       S
*
      SAVEVALUE  24,XH20,H            STORE TOTAL TRANSMISSIONS IN XH24
      PRINT      1,7,Q                PRINT QUEUE STATISTICS AT END OF HR
      TERMINATE  0                    TERMINATE STATISTIC TRANSACTION
*
*  CHANGE DAILY INPUT REQUIREMENTS AND CONTROL SIMULATION RUN TIME
*
      GENERATE   144000,,2,5 STARTING AT REAL TIME=.02 CHANGE DAILY
*                            (1440 MINS) INPUT DATA
      SAVEVALUE  16,FN13,H   DETERMINE NR FIRST RUN MSG TO ARRIVE IN
*                            NEXT DAY (SEE FUNCTION 13)
      SAVEVALUE  17,FN14,H   DETERMINE NR SUBSCRIBERS COPYING NEXT DAY
      SAVEVALUE  23,XH20,H   STORE PREVIOUS DAYS TRANSMISSION TOTAL IN
      SAVEVALUE  20,K0,H      XH23 THEN SET XH20=0
      SAVEVALUE  24,K0,H      AND SET XH24=0
*
      GATE LR    2,SRIA2    IF CHAN2 IS OPEN CALCULATE SCRN REQ MEAN IA
*                           TIME USING V11 IF CHAN2 CLOSED USE V10
      SAVEVALUE  2,V10      CALCULATE SCRN REQ MEAN IA (CHAN2 CLOSED)
      GATE LS    2,TERM     IF CHAN2 IS CLOSED XACT GOES TO TERM
SRIA2 SAVEVALUE  2,V11      CALCULATE SCRN REQ MEAN IA (CHAN2 OPEN)
TERM  TERMINATE  1          TERMINATE DAILY XACT WHEN 5 TRANSACTIONS
      START      5          ARE TERMINATED THE SIMULATION STOPS
      END
```

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

FLEET MULTI-CHANNEL BROADCAST TRAFFIC INTENSITY STUDY

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis, June 1972

5. AUTHOR(S) (First name, middle initial, last name)

Harlan Daryl Oelmann; Lieutenant Commander, United States Navy

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1972	166	15

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

This thesis contains the analysis of data of message traffic loads on the Naval Communications Fleet Multi-channel Broadcast System and results of a simulation model of the system under various channel alignments. Distributions of interarrival times, message lengths and requests for screens and reruns are determined from the data. These distributions are used in a simulation model of the Broadcast System. The model is used to compare the average delays caused by backlogs of messages when two channels devoted to a given ship-type are a) used in series with the second channel used to rebroadcast messages from the first channel after a one hour delay, and b) both channels are used in parallel to transmit first-run messages. The results of the simulation show that backlogs are reduced considerably by running the two channels in parallel at all times.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
COMMUNICATIONS						
NAVAL COMMUNICATIONS						
FLEET BROADCAST						
FLEET MULTI-CHANNEL BROADCAST						
SIMULATION						
QUEUEING						

Thesis 135769
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